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Reclamation on Utah's Emery and Alton Coal Fields: Techniques and Plant Materials

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RESEARCH SUMMARY

The studies reported on in this paper were designed to provide information on methods to establish vegetation on the soils of the semiarid Emery and Alton coal fields in Utah. No large-scale surface mining of coal has occurred in Utah, so research was conducted on typical potential mine sites following severe disturbance of soil materials. At Emery, primary objectives of the several studies were to evaluate the relative merits of site preparation by gouging, harrowing, and cultipacking in conjunction with the use of alfalfa hay or composted conifer bark as soil amendments. Seed was planted by broadcasting in all trials. At Alton, gouging and the use of hay and composted conifer bark was also tested. Wide varieties of plant species, consisting primarily of shrub and grass species but including several forb and tree species, were planted on different soil materials at both coal field locations.

Secondary objectives on both study areas were the evaluation of the use of container-grown shrubs and determination of soil water potentials and soil temperature regimes, as well as a documentation of air temperature and precipitation amounts received during the study period.

During 5 years at Emery and 6 years at Alton, data were obtained on vegetational parameters such as density, percent cover, and plant yield. Data on survival and growth were obtained on planted shrubs.

Major findings at Emery were as follows: The first-year establishment of seeded grasses and shrubs was greater on areas that were lightly harrowed following broadcast seeding than on areas cultipacked following seeding or where seeding and gouging were done simultaneously. However, yields were subsequently higher on areas seeded with the gouger-seeder than on harrowed or cultipacked areas. Grass establishment was enhanced by the incorporation of alfalfa hay into the top 6 to 8 inches (15 to 20 cm) of soil prior to seeding. The addition of composted conifer bark to the soil inhibited initial grass establishment. The yield of perennial grasses was similar on topsoil and subsoil of both the Penoyer and Persayo soil series, whereas grass and shrub establishment on topsoil of the Castle Valley soil series was greatly superior to that on subsoil. The Penoyer soil series supported a more vigorous stand of grasses than soil of the Persayo series. Excellent establishment of container-grown shrub species was obtained at Emery when plants were watered at the time of planting and at 2- to 3-week intervals during the first growing season. Species of *Atriplex* were especially well adapted. Fourwing, Bonneville, broadscale, and trident saltbushes, plus prostrate summercypress, Mediterranean camphorfume, winterfat, and plumed white sage can be recommended for use on all soil materials studied at Emery.

Major findings at Alton were as follows: The incorporation of grass hay into the soil prior to seeding increased the initial establishment of seeded species. However, use of a hay soil amendment in the Alton area is not recommended when topsoil of satisfactory quality is available. Adequate vegetative stand density can be established to protect the soil from erosion on slopes of 15 percent or less by gouging the soil surface followed by broadcast seeding. 'Nomad' alfalfa, fourwing saltbush, bitterbrush, and cliffrose are capable of persisting in competition with perennial grasses on soils of this area, although the latter two species probably won't contribute significant amounts of forage until the fifth or sixth year. "Introduced" species of grass can be expected to outyield "native" species for the first 3 or 4 years following seeding. However, by the fifth or sixth year, well-adapted native species should equal most introduced species in herbage yield. Perennial grass species that appear well adapted to the climate and soils of the Alton coal field are basin wildrye, 'Alkar' tall wheatgrass, 'Whitmar' beardless bluebunch wheatgrass, intermediate wheatgrass, smooth bromegrass, 'Luna' pubescent wheatgrass, 'Fairway' crested wheatgrass, and 'Nordan' crested wheatgrass. Sandy loam topsoil of the fine-loamy Typic Argiustolls subgroup is perhaps best for use on the surface of reclaimed areas of the Alton coal field. A variety of shrub and tree species can be successfully established on soils of this area by planting container-grown seedlings prior to May 15. Supplemental watering should only be necessary at the time of planting. Fourwing saltbush ecotypes from southern Arizona and southern California have little chance to survive in the Utah location because of lack of winter hardiness. Shrub survival and growth are better when shrubs are established in stands of perennial bunchgrass than when forced to compete with vigorous rhizomatous species.

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INTRODUCTION

In the United States today more and more people recognize that fossil fuels must be extracted for the national welfare. As the need for coal increases, additional lands will be mined. In Utah, coal-bearing formations such as those in the Emery and Alton coal fields will be partially or entirely mined from the surface. Surface mining must be done in a manner that minimizes environmental damage. Restoration of vegetative cover on severely disturbed land is usually the only practical, long-term way to stabilize reshaped surface-mined lands and to return them to other productive use. Some areas may be reclaimed in a way that will make them more productive and useful than they were prior to mining.

Areas potentially suitable for the surface mining of coal in Utah are predominantly in arid or semiarid climatic environments, with mean annual precipitation ranging from 7 to 17 inches (180 to 430 mm). Adding to the harshness of the environment is the extreme variability of the precipitation pattern, which often results in lack of adequate soil moisture for seed germination and plant survival. However, high intensity rainstorms in these arid areas necessitate having good vegetative cover to prevent soil loss, downstream flooding, and sedimentation problems.

This report discusses recent research on alternative techniques that could be useful in revegetating lands disturbed by mining in the Emery and Alton coal fields. Because no surface coal mines currently exist on either the Emery or Alton coal fields, this research was limited to treatments that could be applied following severe disturbance with heavy equipment. We hope the results of this work will aid those involved in the planning, operation, use, and management of future mining and revegetation efforts.

PART I: RESEARCH ON THE EMERY COAL FIELD

STUDY AREAS

The Emery coal field lies in central Utah to the east of the Wasatch Plateau, in Emery County. It is in the northwest corner of the Canyonlands section of the Colorado Plateau province (Thornbury 1965). The study area is on the western edge of a region known as the Coal Cliffs, which, in turn, is the western edge of the San Rafael Swell. Individual study sites are located from 4 to 5 mi (6.4 to 8 km) southeast of the town of Emery at elevations between 6,100 and 6,450 ft (1 850 to 1 966 m). Location of these sites is shown in appendix figure 61.

Vegetation on the Emery coal field varies from salt desert shrub communities in the lower areas to pinyon-juniper communities at higher elevations. Typical dominant plant species of local salt desert shrub vegetation are Castle Valley clover (*Atriplex cuneata* A. Nels.), mat saltbush (*Atriplex corrugata* S. Wats.), shadscale (*Atriplex confertifolia* [Torr. & Frem.] S. Wats.), Indian ricegrass (*Oryzopsis hymenoides* [R.&S.] Ricker), greasewood (*Sarcobatus vermiculatus* [Hook.] Torr.), fourwing saltbush (*Atriplex canescens* [Pursh] Nutt.), galleta grass (*Hilaria jamesii* [Torr.] Benth.), blue grama (*Bouteloua gracilis* [H.B.K.] Lag. ex Steud.), alkali sacaton (*Sporobolus airoides* Torr.), and prickly pear (*Opuntia* spp.). As one enters the pinyon-juniper type, characterized by Utah juniper (*Juniperus osteosperma* Hook.) and pinyon (*Pinus edulis* Engelm.), the same grasses are found, plus small shrubs such as black sagebrush (*Artemisia nova* A. Nels.), Bigelow sagebrush (*Artemisia bigelovii* Gray), green ephedra (*Ephedra viridis* Cov.), and corymbed eriogonum (*Eriogonum corymbosum* Benth.).

Soils of the Emery coal field are derived primarily from the Ferron sandstone member of the Cretaceous, Mancos shale formation. The Ferron sandstone is fine to coarse, marine sandstone. All coal in the Emery area occurs in the lower unit of the Ferron sandstone member, which contains intercalated beds of shale, siltstone, and coal. Locally, soils vary from silty clays to loams and very fine sandy loams, having a soil pH range of 7.4 to 8.4, and conductivity values of 2 to 16 mmhos per centimeter. Soils of the individual study sites will be discussed in detail in subsequent sections of this report.

The Emery coal field lies in the rain shadow of the Wasatch Plateau, the northernmost of the High Plateaus of Utah, which rises to the west. Average annual precipitation for most of the coal field area is between 6 and 10 inches (150 and 250 mm). November through April constitutes the driest portion of the year, with each month of the period consistently averaging about 0.45 inches (11.4 mm) of precipitation. May through October constitute the "wet" months, each of which averages about 0.80 inches (20 mm) of precipitation. Historically, August and October have recorded the most precipitation events of 0.2 inches (5 mm) or more. Richardson (1975) says the frost-free growing season averages 132 days at the town of Emery, 6,250 ft (1 905 m) in elevation.

METHODS

On three soil series at Emery, we varied the site preparation and type of soil amendment. We then seeded a mixture of grasses and shrubs believed adapted to the environment. Numerous shrub species and some additional grass and forb species were tested on plots separate from the seeded areas. Data were taken on plant establishment, productivity, and, in the case of shrubs and forbs, on survival and growth rate.

Site Preparation and Soil Amendments

Successful establishment of plants by direct seeding is difficult in areas receiving less than 10 inches (250 mm) of annual precipitation, so we needed to evaluate different methods of seeding. Further, we wanted to know whether the addition of an organic soil amendment would aid plant establishment and growth by increasing available soil moisture and nitrogen. A third objective was to compare the success of selected species of grasses and shrubs sown together.

This phase of the research at Emery was done on each of three different soil series that were found within the area available for research experiments: the Persayo, Penoyer, and Castle Valley series (USDA 1978).

Soils of the Persayo series are calcareous, well drained, and moderately fine textured. They are residual soils, formed from shale, and support a vegetation usually dominated by galleta and shadscale. In a typical profile the surface 1 inch (2.5 cm) is a loam, underlain by up to 12 inches (30 cm) of loam and silty clay loam. The soil is strongly calcareous and mildly alkaline (pH 7.5 to 7.7). The part of the profile below 10 inches (25 cm) is normally silty clay loam that contains less than 35 percent clay. Weathered fragments of shale make up 5 to 70 percent of the material below 10 inches depth.

Soils of the Penoyer series are also calcareous and well drained, but are medium textured. They have formed in alluvium from sandstone, limestone, and basic igneous rocks. Dominant plant species on Penoyer soils are sagebrush, Indian ricegrass, galleta, and shadscale. In a typical profile the surface layer is a strongly calcareous loam about 9 inches (23 cm) thick. Underlying material is loam, silt loam, or very fine sandy loam. The soils are strongly calcareous and mildly to moderately alkaline (pH 7.7 near the surface to 8.2 below). The subsoil below 10 inches contains less than 18 percent clay.

The Castle Valley series consists of shallow, calcareous, well-drained soils found on upland benches and mesas. They have formed from weathered sandstone and interbedded shale, and support pinyon, juniper, big sagebrush, black sagebrush, and Indian ricegrass as the dominant vegetation. In a typical profile the surface layer is a loamy, very fine sand, with a subsoil of gravelly, very fine sandy loam, containing lime in the lower part. The soils are usually shallow with sandstone bedrock at a depth of about 10 inches (25 cm). The soils are slightly calcareous and mildly alkaline (pH 7.6). Flat, angular pieces of sandstone make up from 15 to 50 percent of the volume of the subsoil.

In autumn 1977, three sites were selected and treated: a 6-acre (2.4-ha) tract on Persayo soil, a 4-acre (1.6-ha) tract on Penoyer soil, and a 2-acre (0.8-ha) tract on Castle Valley soil. On both the Persayo and Penoyer sites the topsoil was removed to a depth of 15 inches (38 cm), the subsoil ripped to a depth of 30 inches (76 cm) with a D-9 caterpillar tractor and releveled, and the topsoil replaced. On the Castle Valley soil, approximately 12 inches of topsoil was removed from one-third of the area. This section, and the remaining undisturbed portion of the area were then ripped to a 30-inch depth (fig. 1). No releveling of the ripped soil was attempted, nor was the topsoil replaced where it had been removed.

Figure 1.—Ripping Castle Valley series topsoil to a depth of 30 inches. Persayo and Penoyer subsoils were ripped in a similar manner following removal of 15 inches of topsoil. There the ripped subsoil was releveled and topsoil was replaced prior to seeding. December 1977.

Following the severe soil disturbance on the Persayo site, grass hay was rotovated into a 0.3-acre (0.12-ha) strip across the width of the site (fig. 2), and alfalfa hay was rotovated into the soil on two separate strips, one of 0.63 acre (0.25 ha), and one of 0.44 acre (0.18 ha). In addition, composted conifer bark was rotovated into the soil on a 0.1-acre (0.04-ha) strip across the width of the site. Both types of hay were applied at a rate of 2.5 tons per acre (5.6 tons/ha). The composted bark was spread over the surface of the soil to a depth of 1 inch before being mixed into the soil. The organic soil amendments were tilled into the top 8 inches (20 cm) of soil with a heavy duty rotovator developed at the Forest Service's Missoula Equipment Development Center.

On the Penoyer site, alfalfa hay and composted bark amendments were applied in a similar manner. However, no grass hay amendment was applied. On this site the hay was applied on two 0.36-acre (0.15-ha) strips, and the composted bark on one 0.07-acre (0.03-ha) strip across the width of the test area.

Figure 2.—Rotovating alfalfa hay into the top 8 inches of replaced topsoil on the Persayo soil study area at Emery. December 1977.

Figure 3.—At the Emery study area, seeding and gouging simultaneously with the gouger developed at the Missoula Equipment Development Center. December 1977.

Immediately after the application of organic soil amendments (none were applied to the Castle Valley site), seed mixtures were broadcast on all three sites, as outlined in table 1.

We used three seeding methods on both the Persayo and Penoyer sites: (1) the seed mixture was broadcast, using a hand-operated cyclone seeder, followed by harrowing with a spring tooth harrow; (2) seed was applied as above, followed by firming the seedbed with a small, Brillion cultipacker; and (3) seed was broadcast by a tractor-drawn gouger-seeder simultaneously with the gouging operation of part of the site (fig. 3). Because of the extremely rough, rocky surface of the Castle Valley site, seeding was done entirely with the hand-operated cyclone seeder, and no attempt was made to cover the seed or level and firm the seedbed. For the field design of these studies the reader is referred to appendix figures 41 and 42.

In July 1978, we obtained data on frequency, density, and average blade height of grasses (individual species were not recorded) on each treatment, on both the Persayo and Penoyer sites. At the same time, we recorded data on shrub frequency (all species combined), density of each shrub species, and average height of each shrub species. We used a rectangular-shaped, 10-ft^2 (0.929-m^2) frame placed at a number of randomly chosen locations within each treatment area. The sampling frame was subdivided by cross wires into ten 1-ft^2 (0.093-m^2)subplots. Percent frequency was obtained by recording the number of subplots in which the plant species or plant class being sampled was found, each time the frame was placed down.

In summers 1979 through 1982, vegetative sampling followed the same procedure with the following exceptions: (1) no data were taken on plant density, (2) frequency was recorded for all grasses as a group and for each species of grass and shrub, (3) average culm height was recorded for each grass species, (4) average height was recorded for each shrub species, and (5) yield of each grass and shrub species was estimated by the weight-estimate method (Pechanec and Pickford 1937).

Only visual observations of the results of deep ripping of the Castle Valley soil were made; no quantitative sampling was undertaken.

Table 1.—Composition of seed mixture sown on test sites of Persayo, Penoyer, and Castle Valley soils, Emery coal field

Common name	Scientific name	Source	Lb/acre
'Nordan' crested wheatgrass	*Agropyron desertorum*[1]	South Dakota	3
'Sodar' streambank wheatgrass	*Agropyron riparium*	Canada	3
Russian wildrye	*Elymus junceus*	Montana	3
'Paloma' Indian ricegrass	*Oryzopsis hymenoides*	Utah	2
Alkali sacaton	*Sporobolus airoides*	Kansas	1
Fourwing saltbush	*Atriplex canescens*	Sevier Co., UT	2
Nevada ephedra	*Ephedra nevadensis*	Beaver Co., UT	2
Winterfat	*Ceratoides lanata*	Sanpete Co., UT	2
Shadscale	*Atriplex confertifolia*	Utah	2

[1]Some 'Fairway' crested wheatgrass (*A. cristatum*) was included in the 3 lb/acre on the Penoyer soil.

We used analyses of variance and tests of mean separation to evaluate differences in vegetation results between treatments.

Soil Amendments and Herbaceous Species

We wanted to determine the effects of hay and composted bark amendments on the establishment and growth of selected grass species, and to compare the response of those species to the amendments on both topsoil and subsoil. So in November 1977, we delineated two areas 90 by 210 ft (27 by 64 m), one on the Persayo soil and one on the Penoyer soil. These areas had the topsoil removed and the subsoil ripped as previously described. However, each area was divided in half and topsoil only replaced and leveled on one half, with a 10-ft (3-m) buffer strip between the halves. Alfalfa hay was applied at the rate of 2.5 tons per acre (5.6 tons/ha) and rotovated into the top 8 inches (20 cm) of soil material on two 15-ft wide (4.6-m) strips extending across both the topsoiled and subsoil portions of each area. Composted bark was applied in a similar manner (fig. 4). The remaining one-third of each area served as a control.

On the Persayo soil, seed of 10 selected species was broadcast on subplots 10 by 15 ft (3 by 4.6 m) in size on each of the 15- by 100-ft (3- by 30-m) main plots, resulting in a randomized block, split-plot design with two replications.

Grass species selected for study are known for their adaptability to arid conditions. Species used and amounts of seed sown per plot are shown in table 2.

Seed was broadcast by hand on the loose, rough seedbed left by the rotovator. (The areas on which no soil amendment was applied were also rotovated.) On one of the two replications the subplots were raked with a garden rake following broadcasting of seed; no attempt was made to cover seed on the second replication.

The same species were sown on the Penoyer soil plots, but seed was not sown until March 1978. Soil was roughened by raking with a garden rake, and seed was then broadcast by hand. For the field design of these studies on Persayo and Penoyer soils, the reader is referred to appendix figures 43 and 44.

Figure 4.—Spreading composted conifer bark and alfalfa hay soil amendments on the Penoyer study area at Emery. Compost and hay were rotovated into the top 8 inches of soil prior to seeding. December 1977.

In spring 1978, virtually no seedlings of blue grama, alkali sacaton, or sand dropseed became established on plots of either Persayo or Penoyer soils. These plots were reseeded again in December 1978 with no success. In May 1980, on both the Persayo and Penoyer soils, 6-week-old container-grown plugs of these three species were planted on all subplots previously seeded to those species. Galleta grass was planted on the subplots previously seeded to Palmer penstemon, because the latter had established very poorly on many plots.

Beginning in 1978 we sampled the subplots of the six species of cool-season grasses at the same time and in the same manner as described for the seeding and soil amendment treatments. On each 10- by 15-ft subplot, we took two randomly located samples of 10 ft^2 ($0.929 m^2$) each. In 1981 we took data on the percent survival and

Table 2.—Grass species used and amounts of seed sown on Persayo and Penoyer soils at the Emery coal field

Common name	Scientific name	Source[1]	Lb/acre
'Nordan' crested wheatgrass	*Agropyron desertorum*	South Dakota	10
Hybrid crested wheatgrass	*A. cristatum X A. desertorum*	[2]	10
'Fairway' crested wheatgrass	*Agropyron cristatum*	Montana	20
Russian wildrye	*Elymus junceus*	Montana	20
Indian ricegrass	*Oryzopsis hymenoides*	?	20
Squirreltail	*Sitanion hystrix*	Utah	20
Alkali sacaton	*Sporobolus airoides*	Kansas	10
Sand dropseed	*Sporobolus cryptandrus*	Kansas	10
Blue grama	*Bouteloua gracilis*	Kansas	10
Palmer penstemon	*Penstemon palmeri*	Utah	10
Galleta	*Hilaria jamesii*[3]	New Mexico	10

[1]'Nordan,' 'Fairway,' Russian wildrye, alkali sacaton, sand dropseed, blue grama, and galleta were purchased. The source shown is the State where the species was grown. Squirreltail and penstemon were collected in Utah.

[2]A hybrid between an induced tetraploid form of *A. cristatum* and the tetraploid *A. desertorum*, developed by the USDA Agricultural Research Service at Logan, Utah.

[3]Galleta was not one of the species used in 1977 or 1978. It was planted in May 1980 as container-grown plugs.

mean plant height of transplanted plugs of the four warm-season grass species. In 1982 the same information was obtained for the warm-season species, plus data on yield as determined by the weight estimate method.

No supplemental water was applied to any of the above grass seedings or planting of grass plugs.

Shrub Establishment

Although fourwing saltbush, whitesage, shadscale, and Nevada ephedra had been used in the seed mixture sown on Persayo, Penoyer, and Castle Valley soils, we wanted to learn more about what species of shrubs could be established on the different kinds of soil materials present on the study area.

In April 1978 approximately two dozen species of container-grown shrubs were planted on sites of the Persayo, Penoyer, and Castle Valley soil series, and on a fourth site where the soil material consisted of a clayey, gypsiferous subsoil derived from shale (hereafter referred to as the shaley subsoil site). All except three of these species were members of the family Chenopodiaceae, and the group included three naturally occurring hybrids within the genus *Atriplex*. These plantings were made on both topsoil and subsoil on the Penoyer soil, but on topsoil only on Persayo and Castle Valley soils.

In April 1979 nearly all of the same species were planted on soil material derived from Blue Gate shale. This site had the topsoil removed, the subsoil ripped to a depth of 30 inches (76 cm) and releveled, and the topsoil replaced.

Additional plantings of container-grown stock were made in April of 1979 on Persayo and Castle Valley soils primarily to evaluate other natural and developed hybrids of *Atriplex*. These plantings were made on plots adjacent to the 1978 plantings.

Species were planted in plots 6 by 12 ft (1.8 by 3.6 m) in a randomized-block design, with four replications on each site. Each plot contained two rows of four plants, planted on a 36-inch (0.9 m) grid spacing.

Appendix figures 45 through 51 show field plot designs for the shrub evaluation plantings at Emery. Appendix table 41 lists the species planted on the several study sites, and the origin of each.

All planting stock used in these studies was grown in small containers (most in Spencer-Lemaire, "Rootrainers") in either the Forest Service greenhouse at Provo, Utah, or in the Brigham Young University greenhouse, also in Provo. At Brigham Young University, Dr. Howard Stutz worked under a cooperative research agreement[1] designed to develop new and improved strains of *Atriplex* for use on surface mine reclamation sites. Planting stock was usually 2 to 6 months old when planted at the field site. All plants were watered with 1 qt (0.95 liter) of water at the time of planting. On June 5 and July 20, 1 qt of supplemental water was applied to all plants of the 1978 plantings. The plants on the shaley subsoil site were also given that amount of water on June 29. All plants in two replications at each of the 1978 planting sites were given 2 qt (1.9 liter) of water on August 24 and September 12. The 1979 plantings were provided with supplemental water (1 qt each time) on 10 occasions at 2- to 3-week intervals during summer 1979 to aid establishment. No supplemental water was applied after the first growing season.

Information on some selected soil properties at each of the four major shrub planting sites is given in table 3.

We obtained data on the percent survival and the mean height and diameter of all shrub species in autumn 1978, spring and autumn 1979, autumn 1980, spring and autumn 1981, and autumn 1982.

Table 3.—Properties of soils at the shrub species evaluation sites, Emery coal field

Soil property	Persayo series	Penoyer series	Castle Valley series	Blue Gate shale	Shaley subsoil
Soil reaction (pH)	7.8	8.0	7.7	7.4	7.5
Conductivity (EC_e, mmhos/cm)	3.2	.5	3.8	2.9	5.7
Sodium adsorption ratio (SAR)	4.0	2.0	2.0	1.0	2.7
Cation exchange capacity	5.7	5.7	7.9	8.2	16.4
Saturation percentage	30.0	27.0	37.0	41.0	87.0
Percent moisture at					
0.1 atm	18.0	17.0	22.0	26.0	27.2
0.33 atm	10.0	9.0	14.0	19.0	19.8
15 atm	6.0	5.0	9.0	11.0	12.4
Percent sand	56.0	60.0	44.0	32.0	4.0
Percent silt	25.0	24.0	32.0	57.0	49.0
Percent clay	19.0	16.0	24.0	11.0	47.0
Textural class	SL	SL	L	SiL	SiC

Globemallow and Alkali Sacaton

Scarlet globemallow and alkali sacaton, a forb and a grass respectively, are native species on the Emery coal field. Globemallow is highly palatable to both livestock and deer. Although alkali sacaton is rather coarse and tough after curing, it is quite palatable during the growing season. Our study objective was to evaluate the degree of competition that previously established shrub species would pose for the survival and growth of scarlet globemallow and alkali sacaton on the several different soils present on the study area.

In April 1979, 2-month-old container-grown plants of globemallow and alkali sacaton were planted between the established shrubs on the shrub evaluation plots that had been planted in 1978. We used three replications of the shrub planting sites on Persayo, Penoyer, Castle Valley, shaley subsoil, and Blue Gate shale soils. On one replication, eight globemallow plants were put between the shrubs on each subplot. The second replication had eight sacaton plants on each subplot, and the third replication had four sacaton and four globemallow plants, in alternate fashion. Thus, the shrub species occupying each subplot was to provide competition for either eight globemallow plants, eight sacaton plants, or four of

[1]Memorandum of Understanding, Contract No. 12-11-204-31, between Brigham Young University and Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture.

each. Because of a shortage of globemallow planting stock, only sacaton was planted on the shrub plots located on shaley subsoil. The globemallow and sacaton plants were given 1 qt (0.95 liter) of water at the time of planting, and a similar amount at 2- to 3-week intervals throughout the first growing season.

In September 1980, and in May 1981 and 1982, data were obtained on the survival of the interplanted alkali sacaton and scarlet globemallow.

Native Pinyon and Juniper

Pinyon and Utah juniper trees occur at the higher elevations of the Emery coal field. Both species are slow growing, especially in their first several years of life. On occasion it may be desirable to reestablish some trees on reclaimed areas as rapidly as possible, either for esthetic reasons or to provide a measure of protective cover from the elements for livestock and wildlife.

In late April 1980 an end-loader developed by the Forest Service's Missoula, Mont., Equipment Development Center was used to determine the feasibility of lifting and transplanting pinyon and juniper trees 3 to 10 ft (1 to 3 m) tall. The large bucket of this equipment is 14 ft wide and 9.5 ft deep (4.3 m and 2.9 m). It was developed primarily to lift and transplant blankets of the sod-forming grass species.

Field crews lifted and transplanted 12 pinyon and 19 juniper trees onto a site immediately adjacent to the study area on Persayo soil; 25 pinyon and 19 junipers were lifted and moved 50 to 200 yards (46 to 183 m) on soils of the Penoyer series. On the Persayo site, the trees, with their attached pad of soil, were simply placed on the soil surface at their new location. However, on the Penoyer site, the bucket was used to excavate a spot of similar size and depth to that of the soil and root system mass that was to be received.

Survival of the transplanted trees was monitored in autumn 1980, 1981, and 1982.

Characterization of the Microclimate

In May 1979, a battery-powered (solar-charged) automatic data logger was installed at the Persayo site on the study area. The data logger monitored ambient air temperature 54 inches (137 cm) above the soil surface, soil temperature at depths of 2 and 8 inches (5 and 20 cm) on both the Persayo and shaley subsoil, and precipitation received by an unheated, tipping bucket rain gage. Data were recorded at hourly intervals on magnetic tape.

In addition, thermocouple psychrometers were placed in the soil at depths of 8 and 20 inches (20 and 51 cm) on the Persayo, Penoyer, Castle Valley, Blue Gate shale, and shaley subsoil sites. Soil water potential was monitored on the Blue Gate shale, Castle Valley, and shaley subsoil shrub evaluation sites by implanting the psychrometers at two locations on each site. On both the Persayo and Penoyer soils, psychrometers were placed at six locations—three within the cultipacked treatment and three within the gouged treatment. All psychrometers located on gouged areas were placed in the soil directly below the center of the small pit formed by the gouging action. The psychrometers were read approximately every 3 weeks from June 29 to October 17, 1979. In 1980 and 1981 they were read at monthly intervals from April through October.

RESULTS AND DISCUSSION

After 5 years, grasses and shrubs generally declined in frequency on the study plots. However, all but one species produced more herbage on Penoyer soil than on Persayo soil. Shrub survival was highest on Castle Valley soil. Detailed studies were made of globemallow, alkali sacaton, pinyon, and juniper. Precipitation varied from a drought year to above-average moisture, giving a spectrum of results over the 5-year study.

Site Preparation and Soil Amendments

In spring 1978, seedling emergence was good on all treatments on both the Persayo and Penoyer soils. This may have resulted from 50 percent greater than average winter precipitation, most of which came from January through March 1978. The growing season of 1978 was quite dry. Total precipitation received in the area was only 40 percent of average for the months of April through October, with every month showing less than average precipitation. One storm, in late July, may have been effective in sustaining the young grasses and shrubs; 0.49 inch (12.5 mm) of rainfall was recorded at a gage 1 mile (1.6 km) from the study site.

At the end of the first growing season, frequency of both grasses and shrubs was higher on cultipacked and harrowed areas than on gouged areas of both soil types (table 4). In the case of grasses, this was especially noticeable on the somewhat sandier Penoyer soil.

Table 4.—Mean percent frequency of grasses and shrubs by seedbed preparation treatment on sites of Persayo and Penoyer soil, Emery coal field

Treatment	1978	1979	1980	1981	1982
Persayo soil					
Grasses					
Gouged	70	45	64	59	65
Cultipacked	82	64	78	69	70
Harrowed	77	68	68	78	56
Shrubs					
Gouged	41	28	[2]31	[2]25	[2]23
Cultipacked	44	39	37	33	27
Harrowed	53	54	37	42	55
Penoyer soil					
Grasses					
Gouged	45	[1]41	45	45	46
Cultipacked	70	51	64	59	68
Harrowed	88	72	84	78	73
Shrubs					
Gouged	[3]22	14	6	11	9
Cultipacked	19	8	3	5	5
Harrowed	56	32	28	20	16

[1]Frequency was not obtained for all species of grasses (as a class) on Penoyer soil in 1979. Data for 1979 are for crested wheatgrass only.

[2]Frequency was not obtained for all shrubs (as a class) in 1980, 1981, and 1982 on Persayo soil. Data for these 3 years represent the sum of frequency values of all four shrub species.

[3]Frequency of all shrubs (as a class) on Penoyer soil was only recorded in 1978. Data for other years represent the sum of frequency values of all four shrub species.

Harrowing lightly, immediately after broadcast seeding, was clearly the most favorable of the three surface treatments for shrub establishment (fig. 5). Even after 5 years, shrub frequency was still highest on the harrowed areas of both the Persayo and Penoyer soils.

Figure 5.—Excellent establishment of Ceratoides lanata *and* Atriplex confertifolia *was obtained on area of Persayo and Penoyer soils when broadcast-seeding was followed by light harrowing. October 1978.*

Seedling establishment resulting from lightly harrowing Persayo and Penoyer soils after broadcasting seed was better than the results from the cultipacking or gouging treatments. In the gouging procedure, the seed was dispensed from the hopper and fell onto the newly gouged soil surface, where seed was only likely to be covered by soil in the gouged pit. Little seedling establishment occurred on the ridges between pits. Cultipacking, which in this case was done after seed was broadcast, served to press the seed into the surface of the loose soil. However, it left a smooth surface, where any seed not anchored in the soil was subject to movement by wind. Winterfat, which has a light, feathery utricle, was noticeably more abundant on the harrowed areas than on gouged or cultipacked areas (fig. 5).

On Persayo soil, after 2 years, mean yields were higher on gouged areas than on harrowed or cultipacked areas, and with the exception of 1981, remained slightly higher. However, statistical analyses of the 1982 data gave no evidence to support a claim of differences between treatments. On Penoyer soil, yields on gouged areas were equal to those on harrowed and cultipacked areas by the third year, and appeared to be slightly higher after 5 years. Shrub yield seemed to be higher, initially, on harrowed areas, but the differences between harrowed, gouged, and cultipacked areas appear to be diminishing with time (table 5).

Table 5.—Mean yield (lb/acre, air–dry) of grasses and shrubs by seedbed preparation treatment on sites of Persayo and Penoyer soil, Emery coal field

Treatment	1979	1980	1981	1982
Persayo soil				
Grasses				
Gouged	130	908	278	338
Cultipacked	88	813	292	223
Harrowed	91	644	241	265
Shrubs				
Gouged	[1]—	358	73	82
Cultipacked	—	343	68	71
Harrowed	—	398	55	130
Penoyer soil				
Grasses				
Gouged	442	1,700	711	616
Cultipacked	508	1,716	616	555
Harrowed	768	1,685	428	455
Shrubs				
Gouged	85	144	43	122
Cultipacked	60	41	25	21
Harrowed	203	294	25	41

[1]No yield data were obtained in 1979.

The primary benefit from gouging is the retention of precipitation (both rain and snow) on the treated area, rather than losing rain by overland flow and snow by being blown from a bare, level soil surface. In an arid region, plants benefit greatly from relatively small increases in available soil moisture. At Emery, the pits formed by gouging did serve to retain precipitation, as reflected by higher soil water potential measurements from psychrometers under gouged pits. Pits formed by gouging on the study areas were still fairly stable after 5 years.

The establishment of grasses was enhanced by the addition of a hay amendment to the soil (table 6). Conversely, where grasses established well, shrub establishment was inhibited. However, by the fifth year percent frequency of grasses on the Penoyer soil was essentially the same on hay-amended, compost-amended, and control areas, although shrub frequency was still lowest on hay-amended areas. On Persayo soil, differences in percent frequency of grasses diminished with time (table 6), whereas shrub frequency remained highest on nonamended areas. Frequency of occurrence was not only higher on the hay-amended portions of the 6-acre (2.4-ha) and 4-acre (1.6-ha) areas, where a seed mixture was sown, but also on the small plots where individual species of grasses were tested. Although yields were generally greater on hay-amended areas in the second and third growing seasons (except on the main area of Penoyer soil in 1979), only in the latter year were differences statistically significant (table 7). By the fifth year, on both soil types, yield of both grasses and shrubs were similar regardless of amendment treatments.

Table 6.—Mean percent frequency of grasses and shrubs by soil amendment treatment on sites of Persayo and Penoyer soil, Emery coal field

Treatment	1978	1979	1980	1981	1982
Persayo soil					
Grasses					
Hay	85	66	81	70	71
Compost	68	36	65	56	65
Control	70	54	63	65	62
Shrubs					
Hay	39	30	[2]29	[2]25	[2]16
Compost	54	28	42	30	21
Control	46	46	38	37	45
Penoyer soil					
Grasses					
Hay	73	[1]58	68	61	62
Compost	63	52	62	62	64
Control	66	53	63	59	61
Shrubs					
Hay	[3]26	5	3	3	4
Compost	32	15	13	15	7
Control	38	34	21	19	18

[1]Frequency was not obtained for all species of grasses (as a class) on Penoyer soil in 1979. Data for 1979 are for crested wheatgrass only.

[2]Frequency was not obtained for all shrubs (as a class) in 1980, 1981, and 1982 on Persayo soil. Data for these 3 years represent the sum of frequency values of all four shrub species.

[3]Frequency of all shrubs (as a class) on Penoyer soil was only recorded in 1978. Data for other years represent the sum of frequency values of all four shrub species.

Of the four shrub species used, winterfat (*Ceratoides lanata* [Pursh] J. T. Howell) occurred most frequently in the young stand, constituting 55 percent of the shrub population on both soil types. Shadscale made up 35 percent of the first-year shrub stand on Penoyer soil, followed by fourwing saltbush and Nevada ephedra (*Ephedra nevadensis* Wats.) with 5 percent each. On Persayo soil, winterfat was followed in percent composition of the shrub population by shadscale (17 percent), Nevada ephedra (14 percent), and fourwing saltbush (13 percent). After 5 years, shadscale was the most frequent shrub on Persayo soil, whereas on Penoyer soil, winterfat, shadscale, and fourwing saltbush were nearly equal in frequency. Fourwing saltbush and winterfat both appear to grow more vigorously on Penoyer soils than on Persayo soils. Nevada ephedra did not exhibit good growth on either soil, at least not in competition with grasses.

Table 7.—Mean yield (lb/acre, air-dry) of grasses and shrubs by soil amendment treatment on sites of Persayo and Penoyer soil, Emery coal field

Treatment	1979	1980	1981	1982
Persayo soil				
Grasses				
Hay	114	1,105	293	266
Compost	161	796	297	337
Control	81	566	259	272
Shrubs				
Hay	[1]—	278	53	47
Compost	—	502	120	77
Control	—	388	67	117
Penoyer soil				
Grasses				
Hay	517	2,198	524	551
Compost	595	1,739	590	548
Control	607	1,164	641	527
Shrubs				
Hay	27	96	17	78
Compost	88	146	34	46
Control	233	236	43	59

[1]No yield data were obtained in 1979.

During the 5 years of study both grasses and shrubs declined in percent frequency (table 4). However, crested wheatgrass maintained its dominant position on both soils and decreased little in percent frequency. Russian wildrye remained the second highest grass species in terms of percent frequency, on both soils, but decreased nearly 50 percent in frequency over the 5 years. This species is favored by good early spring moisture and was especially vigorous on the deeper, Penoyer soil area in 1982.

Soil Amendments and Herbaceous Species

Alfalfa hay and composted conifer bark were also tested on small plots as soil amendments with 10 species of grass and one forb. All species were established on both topsoil and subsoil of the Persayo and Penoyer soil series.

In spring 1978 seedling establishment of the six "cool season" grass species was good. However, the four "warm season" grasses failed to germinate, and in May 1980 were established from container-grown planting stock. The lone forb, Palmer penstemon, germinated sporadically but by the second year had established quite well on several plots.

In the first growing season, percent frequency and seedling density of the cool season grasses were greatest on hay-amended plots of the topsoil of both Persayo and Penoyer soils, although the differences may not have been statistically significant. On subsoil plots, little difference existed between hay-amended and control

plots. The addition of a composted bark soil amendment seemed to decrease grass establishment in every case. Although the overall mean percent frequency of young plants was similar on topsoils and subsoils, the former produced taller plants than the latter.

In the second year, data analyses indicated that plant frequency was still significantly lower on compost-amended plots of both Persayo and Penoyer soils. On Persayo soil, overall yield of grass was significantly higher on topsoil than on subsoil, but there was no difference between yields on Penoyer topsoil and subsoil. Yields were not significantly different according to soil amendment treatment on either Persayo or Penoyer soil.

In the third growing season (1980) yields were significantly higher on hay-amended plots than on compost-amended or control plots (table 8). In 1980, a year of exceptionally high soil moisture in the early part of the growing season, grasses on hay-amended plots were darker green in color than grasses on compost-amended or control plots. Laboratory analyses of herbage samples showed that grasses growing on hay-amended plots contained 1.3 to 3 times as much nitrogen as grasses growing on the other treatment plots. The darker green color on hay-amended areas was apparent on both the Persayo and Penoyer soils, and also on the larger areas of both soils where the seed mixture had been used (figs. 6 and 7). The color was still apparent in the fifth year.

Table 8.—Combined yield (lb/acre, air-dry) of six species of cool season grasses by soil amendment treatment on Persayo and Penoyer soils, Emery coal field

Soil and year	Treatment: Hay	Compost	Control
Persayo soil			
1979	572	336	358
1980	646	435	399
1981	309	308	300
1982	232	203	284
Penoyer soil			
1979	303	119	242
1980	873	536	792
1981	363	331	378
1982	568	375	470

Percent frequency decreased on both Persayo and Penoyer soils in the fourth year, 1981, which was a dry growing season (table 5). In 1982, percent frequency rebounded to 1980 levels on the Penoyer soil but remained somewhat lower than the 1980 level on the Persayo soil.

Yields also decreased sharply in 1981 on all treatments of both soil series. In 1982, yields made some recovery on Penoyer soil but declined even further on Persayo soil (table 8).

Of the 10 species evaluated on the small plots, the three wheatgrasses, Russian wildrye, and squirreltail grass exhibited good seedling establishment on Persayo soil. On the Penoyer soil the three wheatgrasses were highest in percent frequency the first year. As previously mentioned, none of the three warm season grasses showed sufficient seedling emergence to warrant continued observation.

Figure 6.—Seeded grasses were more vigorous and were darker green in color in the third growing season on areas where alfalfa hay had been rotovated into the top 8 inches of soil. June 1980.

From the second through the fifth years, the induced hybrid crested wheatgrass and Russian wildrye each exhibited a smaller decrease in percent frequency than the other cool season grasses on Persayo soil. On Penoyer soil during the same time period, Indian ricegrass changed from lowest to highest in percent frequency while squirreltail grass steadily decreased (table 9).

Figure 7.—Photo taken in September 1981 from same point as shown in Figure 6. Seeded grasses "greened up" following 2.64 inches (6.7 cm) of rain on the area where alfalfa hay soil amendment had been used in autumn 1977.

Table 9.—Percent frequency of six cool season grasses on small plots of Persayo and Penoyer soil, Emery coal field

Grass	1978	1979	1980	1981	1982
Persayo soil					
'Nordan' crested wheatgrass	89	81	68	59	59
'Fairway' crested wheatgrass	95	94	76	69	72
Crested wheatgrass hybrid	94	95	84	80	80
Russian wildrye	96	91	85	80	77
Indian ricegrass	77	49	45	32	35
Squirreltail grass	91	86	72	60	65
Penoyer soil					
'Nordan' crested wheatgrass	81	87	74	67	72
'Fairway' crested wheatgrass	89	88	63	55	60
Crested wheatgrass hybrid	92	88	68	55	70
Russian wildrye	68	84	66	55	67
Indian ricegrass	53	70	67	64	78
Squirreltail grass	62	72	35	29	32

Yield of the individual grass species reached a peak in the third growing season, except for Indian ricegrass, which has shown an increase with time (table 10). By the fifth year, Indian ricegrass had become the highest yielding species on both Persayo and Penoyer soils (fig. 8). Beginning with the third year, all species except squirreltail grass produced more herbage on Penoyer soil than on Persayo soil. Mean yields were greater on Penoyer soil in 1982 than in 1981 (except for squirreltail grass), but yields of all species except Russian wildrye continued to decline on Persayo soil. The growing season of 1982 was a good one for Russian wildrye because of good early season soil moisture, which the early developing wildrye was able to take advantage of.

Table 10.—Mean yield (lb/acre, air-dry) of six cool season grasses on Persayo and Penoyer soils, Emery coal field

Grass	1979	1980	1981	1982
Persayo soil				
'Nordan' crested wheatgrass	510	666	310	245
'Fairway' crested wheatgrass	568	549	302	193
Crested wheatgrass hybrid	675	724	289	226
Russian wildrye	350	447	250	282
Indian ricegrass	104	193	394	336
Squirreltail grass	327	380	290	155
Penoyer soil				
'Nordan' crested wheatgrass	360	1,078	382	491
'Fairway' crested wheatgrass	229	882	418	455
Crested wheatgrass hybrid	498	1,051	464	532
Russian wildrye	109	601	295	468
Indian ricegrass	58	550	494	790
Squirreltail grass	73	252	93	89

Figure 8.—An excellent growth of Oryzopsis hymenoides *on the small test plots of individual species on Penoyer soil. June 1982.*

Warm Season Grasses and Palmer Penstemon

Percent survival of the four species of warm season grasses, established on the small plots in May 1980 by planting container-grown plugs, is shown in table 11. Only where the grass plugs were planted adjacent to plots of well-established cool season grasses was mortality evident in the first year, 1980. Alkali sacaton was the most vigorous of the four species on both soil series, although blue grama also showed good vigor on the Penoyer soil. All species on Penoyer soil were subjected to severe competition from the annual weed *Kochia scoparia* (L.) Schrad. (summer cypress). At times, surviving plants were difficult to locate in 1981. The hay and composted bark soil amendments that had been applied at the beginning of the study (1977) had no effect on survival of these warm season grasses.

Table 11.—Percent survival of four warm season grasses established from plug transplants, Emery coal field

Grass	1981	1982
Persayo soil		
Blue grama	94	90
Alkali sacaton	94	91
Sand dropseed	91	73
Galleta	86	79
Penoyer soil		
Blue grama	86	81
Alkali sacaton	76	74
Sand dropseed	68	72
Galleta	66	57

Yield data obtained in 1982 by the weight-estimate method indicated that alkali sacaton produced the greatest amount of herbage on both soil series (table 12). However, this species should be expected to yield more than blue grama and galleta because the latter two are by nature much smaller in stature in the Emery area. Three of the four species showed higher yields on Penoyer soil than on Persayo soil. Yields of galleta grass were similar on the two soils.

Table 12.—Mean yield (lb/acre, air-dry) of four warm season grasses on two soil series in the third year, Emery coal field

Series	Alkali sacaton	Blue grama	Galleta	Sand dropseed
Persayo soil	228	118	158	105
Penoyer soil	293	214	164	241

Palmer penstemon, which had been seeded in autumn 1977 on plots of both Persayo and Penoyer soil, established well on several plots after germinating in spring 1979. It survived well and reproduced from seed through the next 4 years (fig. 9).

Figure 9.—Excellent plot of Penstemon palmeri *established by broadcast seeding on Penoyer soil in spring 1978. Photo taken July 9, 1982.*

Seeding of Ripped Castle Valley Topsoil

No data were taken on the 2 acres (0.8 ha) of ripped Castle Valley topsoil. However, after 5 years the portion of the area where the topsoil was not removed supported a good mixture of grass and shrubs, mostly shadscale (fig. 10).

Figure 10.—A good stand of perennial grasses and shrubs in the fifth year following deep ripping and broadcast seeding on Castle Valley soil, Emery study area. July 9, 1982.

In sharp contrast, after 5 years the area from which the top foot of topsoil was removed supported an extremely sparse stand of seeded shrubs and grasses (fig. 11).

Figure 11.—A poor stand of perennial grasses and shrubs in the fifth year following removal of 12 inches of topsoil, ripping to a depth of 32 inches, and broadcast seeding on Castle Valley soil at the Emery study area. July 9, 1982.

Shrub Establishment

Container-grown shrubs survived well and made excellent growth during the first growing season (1978) on all soils except the shaley subsoil. Supplemental water increased plant survival only on shaley subsoil. Average height of plants at the end of this season was 3 inches (7.6 cm) greater on Castle Valley soil than on the other three sites. Plants on shaley subsoil plots averaged only half the growth of plants on Persayo and Penoyer soils.

Table 13 shows the mean percent survival of shrubs planted on five sites after 5 years. The planting on the Blue Gate shale site was made in 1979.

Over the 5 years of observations, overall survival was highest on Castle Valley soil and lowest on Persayo soil. The reason for the higher survival on Castle Valley soil is not definitely known but could be due to either a slightly greater clay content than that of the other soils (except for the shaley subsoil) or to the fact that the plots of Castle Valley soil were constructed by spreading a layer of this topsoil to a depth of between 3 and 4 ft (0.9 and 1.2 m) deep.

Although first-year mortality was high on the shaley subsoil, few plants succumbed in the subsequent 4 years. Plants on this site faced virtually no competition, because invasion by native species was extremely sparse (fig. 12). On the other hand, shrubs on the Persayo soil faced considerable competition from Russian wildrye, crested wheatgrass, and some shadscale, all of which became established from seed blown onto the area when the adjacent 6-acre (2.4-ha) study area was broadcast seeded (fig. 13).

Atriplex navajoensis was the only shrub species to exhibit lack of winter hardiness, failing completely on three of the four sites on which it was planted.

The 1979 growing season was extremely dry. Many shrub species showed signs of moisture stress by September, and mortality was evident by early spring 1980.

Most species showed little increase in size after the second year. Because all except three of the species tested were chenopods, they will most likely grow rapidly during the first couple of years to a size near maximum for the environment of the Emery coal field.

Table 13.—Mean percent survival of shrub species on five soil types at the end of the fifth growing season, Emery coal field

	Soil types					
Species symbol[1]	Shaley subsoil	Persayo topsoil	Penoyer topsoil	Castle Valley topsoil	Blue Gate shale topsoil	Mean for all soils
ARNO	44	70	81	62	np	64
ATAP	38	25	44	38	81	45
ATBO	78	75	78	94	78	81
ATCA	81	19	66	69	94	66
ATCA x ATCU	96	31	88	88	78	76
ATCA x ATID	59	np	69	np	47	58
ATCA x ATTR	62	np	38	100	34	58
ATID	np	50	np	91	72	71
ATOB	75	84	84	100	75	84
ATRO	25	38	0	95	12	34
ATTO	50	19	44	65	np	44
ATTR 1	62	56	78	100	97	79
ATTR 2	78	25	84	88	84	72
ATNA	0	0	0	56	np	14
CAMO	81	84	50	74	97	77
CELA	66	91	84	97	84	84
CEPA	72	np	91	100	94	89
EPNE	56	53	97	91	np	74
ERCO	62	22	3	np	np	29
GRSP	44	56	72	92	np	66
KOPR 4	96	84	75	88	97	88
KOPR 7	100	np	94	np	100	98
KOPR 9	100	np	100	np	np	100
KOPR 11	np	97	np	97	np	97
KOPR 12	np	94	np	100	100	98
Mean	68	57	69	85	78	70

[1]See appendix table 41 for list of species and original source, if known. See appendix table 69 for plant symbol key.
np = species not planted on this site.

Figure 12.—Shrub evaluation planting on shaley subsoil material at the Emery study area. Note the absence of any invading plant competition. August 1980.

Figure 13.—Shrub evaluation planting on Persayo topsoil at the Emery study area. Severe competition from Russian wildrye and crested wheatgrass exists on the area. July 1982.

The three nonchenopod species (ephedra, black sagebrush, and corymbed eriogonum) have shown additional increase in size each year, although all have grown slowly. Table 14 shows mean height and diameter of all species tested at the end of 5 years. Most species were most vigorous on the Penoyer soil and exhibited slowest growth on shaley subsoil and Blue Gate shale soils.

The criterion of size attained does not always reveal which shrub species are well adapted to a certain soil type. Corymbed eriogonum occurs primarily on shaley

Table 14.—Mean height and mean canopy diameter (inches) of shrub species after 5 years on five soil types, Emery coal field

Species symbol[1]	Shaley subsoil		Persayo topsoil		Penoyer topsoil		Castle Valley topsoil		Blue Gate shale topsoil	
	Ht.	*Dia.*	*Ht.*	*Dia.*	*Ht.*	*Dia.*	*Ht.*	*Dia.*	*Ht.*	*Dia.*
ARNO	4	6	8	8	12	15	7	8	—np—	
ATAP	5	8	16	24	9	14	7	11	4	7
ATBO	8	12	10	15	16	23	14	20	7	9
ATCA	11	14	18	19	16	21	12	17	10	12
ATCA x ATCU	12	14	12	17	22	27	12	17	5	7
ATCA x ATID	5	7	—np—		11	15	—np—		5	7
ATCA x ATTR	6	10	—np—		10	14	10	16	3	6
ATID	—np—		8	15	—np—		10	16	6	8
ATOB	7	9	11	12	7	9	10	18	5	7
ATRO	3	4	4	7	0	0	6	10	5	5
ATTO	5	6	12	15	7	11	6	12	—np—	
ATTR 1	4	9	9	14	7	12	9	16	5	10
ATTR 2	8	12	9	11	10	13	10	16	5	9
ATNA	0	0	0	0	0	0	10	15	—np—	
CAMO	4	13	7	10	11	15	11	13	4	12
CELA	6	6	9	11	12	16	11	15	9	11
CEPA	6	7	—np—		16	24	9	11	10	10
EPNE	5	6	7	7	11	14	9	8	—np—	
ERCO	9	12	8	13	13	22	—np—		—np—	
GRSP	4	5	9	10	10	14	10	14	—np—	
KOPR 4	6	14	20	19	18	24	19	21	7	16
KOPR 7	6	15	—np—		18	22	—np—		6	14
KOPR 9	5	14	—np—		19	26	—np—		—np—	
KOPR 11	—np—		17	16	—np—		14	16	—np—	
KOPR 12	—np—		17	16	—np—		17	20	6	12
Mean	6	10	11	14	13	18	11	15	6	10

[1]See appendix table 41 for species list and original source, if known. See appendix table 69 for plant symbol key.
np = not planted on this site.

soil of high clay content on the Emery coal field. Indeed, survival of planted eriogonum was much higher on the shaley subsoil than on either Persayo or Penoyer soil. However, the few plants that survived on the sandy loam, Penoyer soil have grown well. *Atriplex tridentata* appears to thrive somewhat better on Persayo soil than on Penoyer soil. Black sagebrush does not appear well adapted to shaley, clayey soil.

Mediterranean camphorfume, prostrate summer-cypress, and trident saltbush grew well on all soils on which they were planted (figs. 14 and 15). Broadscale saltbush performed nearly as well on all soils. Winterfat seems well adapted to Penoyer soil (fig. 16) and only slightly less adapted to Castle Valley and Blue Gate soils. Other species that should prove useful on particular soils are fourwing saltbush, plumed whitesage, Bonneville saltbush, black sagebrush, and hybrids of fourwing saltbush with cuneate saltbush (*Atriplex cuneata* A. Nels.) (fig. 17) and with trident saltbush.

Figure 14.—Good plant of Camphorosma monspeliaca, *an introduction from the U.S.S.R., growing on Blue Gate shale soil material. The plant is in the fourth growing season. August 1982.*

Figure 16.—Excellent plants of Ceratoides lanata *at the end of the first growing season on Penoyer topsoil. October 1978.*

Figure 15.—Excellent plants of Kochia prostrata, *an introduction from the U.S.S.R., growing on Penoyer topsoil. Plants are in the second growing season. August 1979.*

Figure 17.—Excellent growth of Atriplex canescens x Atriplex cuneata *hybrid in the second growing season on Penoyer topsoil. August 1979.*

Table 15.—Mean percent survival of shrub species on Persayo and Castle Valley soils after each of the first four growing seasons, Emery coal field

Species symbol[1]	Persayo soil 1979	Persayo soil 1980	Persayo soil 1981	Persayo soil 1982	Castle Valley soil 1979	Castle Valley soil 1980	Castle Valley soil 1981	Castle Valley soil 1982
ATBO x ATTR	98	97	94	94	100	100	100	100
ATCA (Yuma)	94	9	3	0	100	41	41	41
ATCA (Jericho)	94	50	44	22	94	44	25	12
ATCA x ATCO x ATCA	88	53	34	31	90	84	78	72
ATCA x ATOB	100	78	78	78	100	88	88	88
ATCA x ATID	100	94	88	88	np	—	—	—
ATCA x ATTR	98	69	53	50	98	88	88	88
ATCU x ATCO	np	—	—	—	78	67	67	63
ATFA	75	0	—	—	90	88	84	81
ATID	np	—	—	—	100	100	94	94
ATLA	100	84	75	75	100	100	100	100
ATRO	88	62	31	31	np	—	—	—
CEPA	100	100	94	91	np	—	—	—

[1]See appendix table 41 for scientific names and geographic source. See appendix table 69 for plant symbol key.
np = not planted on this site.

1979 Plantings

Supplemental watering on 10 occasions during the first growing season (1 qt or 1 liter/plant) resulted in excellent survival of most *Atriplex* accessions that year (table 15). Seven of eight accessions common to both the Castle Valley and Persayo plots showed higher survival on the Castle Valley soil after 4 years. Although several of these saltbush species and hybrids survived reasonably well, especially on the Castle Valley soil, growth of most has been quite slow (table 16). After 4 years, only the hybrids of *Atriplex canescens* with *Atriplex idahoensis* (the latter an undescribed taxon) and *Atriplex bonnevillensis* with *Atriplex tridentata* show promise of being useful plants on these soils. However, continued observations for a few more years should be made before final judgment is passed. The two accessions that seem least adapted on these sites are fourwing saltbush from Yuma, Ariz., and the gigas accession of fourwing saltbush from sand dunes near Jericho, Utah.

Table 16.—Mean height and crown diameter (inches) of shrub species on Persayo and Castle Valley soils after 4 years, Emery coal field

Species symbol[1]	Persayo soil Height	Persayo soil Diameter	Castle Valley soil Height	Castle Valley soil Diameter
ATBO x ATTR	8	11	10	14
ATCA (Yuma)	ns	ns	6	7
ATCA (Jericho)	7	5	8	4
ATCA x ATCO x ATCA	4	9	7	8
ATCA x ATOB	4	8	4	6
ATCA x ATID	8	15	np	np
ATCA x ATTR	6	9	4	6
ATCU x ATCO	np	np	2	5
ATFA	ns	ns	6	8
ATID	np	np	8	9
ATLA	5	6	6	7
ATRO	2	2	np	np
CEPA	8	11	np	np
Means	6	8	6	7

[1]See appendix table 41 for scientific names and geographic source. See appendix table 69 for plant symbol key.
np = not planted on this site.
ns = no survival of this species.

Globemallow and Alkali Sacaton

The addition of approximately 1 qt (0.95 liter) of supplemental water to each plant on eight occasions during the first growing season was sufficient to obtain excellent first-year survival of globemallow and alkali sacaton planted between established shrubs. Initial survival of sacaton was highest on shaley subsoil. Excellent survival on this clayey soil material may be explained by its high moisture-holding capacity and a minimum of competition with the established shrubs (shrubs on this soil have grown slowly). After 4 years, survival and vigor of sacaton remained best on the shaley subsoil and poorest on Persayo soil (table 17).

Table 17.—Survival of alkali sacaton and four accessions of globemallow on different soil types in fifth growing season, when interplanted with established shrubs, Emery coal field

Soil type	Alkali sacaton	Globemallow accessions			
		Gunnison	D.E.R.[1]	Alton	Ouray
Blue Gate topsoil	75	39	27	57	[2]np
Penoyer topsoil	92	82	85	72	65
Persayo topsoil	65	43	47	56	29
Castle Valley topsoil	68	58	57	35	np
Shaley subsoil	99	np	np	np	np
Mean		56	54	55	47

[1]D.E.R. = Desert Experimental Range, Millard County, Utah.
[2]np = not planted on this soil.

By early summer of the fifth growing season, 1983, globemallow survival seemed affected more by site than by the species of shrub growing near it. Survival of globemallow was highest on the Penoyer soil type, and lowest on the Blue Gate soil (table 17). There was little difference in mean survival of globemallow accessions across all sites, although soil type seemed to influence survival of the four accessions.

The species of shrub with which globemallow had to compete had relatively little effect on globemallow survival except for the severe competition of prostrate summercypress. In competition with five accessions of summercypress, globemallow averaged 30 percent survival (range of 20 to 38 percent), whereas in competition with 20 other shrub species, globemallow averaged 60 percent survival (range of 42 to 78 percent).

All four accessions of globemallow exhibited some vigorous individuals on each of the sites on which they were planted. Because plant size can be largely determined by genetic characteristics, it is difficult to compare the relative sizes of the globemallow accessions on the Emery planting sites. However, plants of the Ouray source (Uintah County) were the smallest in stature among the accessions planted on Persayo and Penoyer soils (table 18).

Prostrate summercypress provided severe competition for both alkali sacaton and globemallow, not only from the original eight summercypress plants on each plot, but also from large numbers of small, new plants of summercypress resulting from seed dispersal.

Table 18.—Mean size (inches) of four accessions of globemallow on each of four soil types in the fifth growing season, Emery coal field

Accession	Soil type							
	Penoyer		Castle Valley		Blue Gate		Persayo	
	Ht.	*Dia.*	*Ht.*	*Dia.*	*Hi.*	*Dia.*	*Ht.*	*Dia.*
Gunnison	12.0	9.4	11.8	7.7	10.4	8.0	6.3	5.3
D.E.R.[1]	12.6	12.5	11.8	10.3	7.7	6.2	5.9	4.5
Alton	13.2	12.6	8.9	7.8	10.5	10.2	6.2	4.4
Ouray	10.3	12.0	[2]np		np		5.3	3.4

[1]D.E.R. = Desert Experimental Range, Millard County, Utah.
[2]np = not planted on this soil.

Transplanting Local Pinyon and Juniper

In late April 1980, 19 Utah juniper and 12 pinyon trees were lifted and transplanted to a site near the Persayo-soil study area; 25 pinyons and 19 junipers were transplanted at the Penoyer-soil study area (fig. 18). Transplanted pinyons ranged from 1 to 11 ft (0.3 to 3.4 m) in height, with crown diameters from 1 to 10 ft (0.3 to 3 m). Transplanted junipers ranged from 1.5 to 9 ft (0.5 to 2.7 m) in height and from 1.5 to 10 ft (0.5 to 3 m) in crown diameter. A layer of soil 1.5 to 2.5 ft (0.5 to 0.8 m) deep was excavated with each tree (7 to 11.6 yd^3 or 5.4 to 8.9 m^3).

Figure 18.—Placing an 8-foot tall pinyon tree in a new location after lifting and moving with a large front-end loader. April 1980.

Mortality during the first summer following transplanting was 29 percent among junipers and 22 percent among pinyons. By the end of the third year following transplanting, 42 percent of the junipers had died compared to 24 percent of the pinyons.

Junipers 5 ft (1.5 m) or more in height suffered a 56 percent mortality, whereas mortality among pinyon trees 5 ft or more in height was 39 percent. Among juniper

trees less than 5 ft in height, mortality was 32 percent. All pinyons less than 5 ft tall and junipers less than 3 ft (0.9 m) tall survived (fig. 19).

Figure 19.—All visible juniper and pinyon trees on the flat area in the foreground were transplanted with a large front-end loader. Five months later, several of the larger trees were dead.

Characterization of the Microclimate

The automatic data logging system installed at the 6-acre (2.4-ha) Persayo soil study area in May 1979 functioned almost flawlessly. Occasional summer electrical storms resulted in some brief periods when the date and time of day were recorded incorrectly. However, no data were lost, and a scan of sequential data passes enabled corrections of incorrectly recorded date and time. One soil temperature sensor became defective in the third week of November 1981 and was not replaced.

Appendix tables 42 through 45 show summaries of air and soil temperature data obtained over 40 months.

Energy, Minerals, Rehabilitation, Inventory and Analysis (EMRIA) Report No. 16 (Hodder and Jewell 1979) shows the mean annual temperature for the town of Emery as 45.8° F (7.7° C). The mean annual temperature for the 2 years for which we have complete data at the Emery study area was 49.3° F (9.6° C) in 1980 and 50.5° F (10.3° C) in 1981. This would indicate that the mean temperature is somewhat warmer at the study area, despite its 70-ft (20-m) higher elevation. The monthly mean temperatures at the town of Ferron are shown in appendix table 46. For the years 1980 through 1982, the mean annual temperature as measured at Ferron, the nearest currently maintained National Oceanic and Atmospheric Administration (NOAA) weather station, was less than 1.8° F (1° C) lower than the mean annual temperatures measured at the study area. The elevation at the Ferron weather station is 390 ft (119 m) lower than the study area.

Hodder and Jewell (1979), citing Richardson (1975), give the mean frost-free growing season as 132 days. However, as is the case with precipitation, the frost-free period varies greatly in the region of the Emery coal field. Freezing temperatures have been recorded in every month except July. From 1938 through 1981, the frost-free growing season averaged 126 days, with a range of 74 to 165. Mean dates of last spring frost and first autumn frost have been May 24 and September 28, respectively. In reality, however, a day in May or June that shows a minimum temperature of 32° F (0° C) does not "shorten" the growing season for most of our native plants. Once growth begins in the spring, freezing or subfreezing temperatures may cause some damage to young plant tissue, but growth continues unless the plant's entire aboveground part has been killed. The "growing season" for most native plants should be based on certain threshold temperatures of the air and soil. Different plant species will have different threshold temperatures. Appendix table 47 shows the length of frost-free period, and other miscellaneous microclimatic data for the Emery study area, for the years 1978 through 1982.

Appendix table 48 presents a comparison of the "growing degree days" (GDD) using a base temperature of 40° F (4.4° C) and an upper level of 78.8° F (26° C) for the years 1979 through 1982 at the study area.

For these calculations, the growing degree days for each day were determined using the equation:

$$GDD = \frac{(\text{daily max. temp} \leq 78.8^\circ + \text{daily min. temp} \geq 40^\circ)}{2} - 40$$

That is, whenever the maximum temperature for a given day is higher than 78.8° F, then 78.8° F is used in the equation. Similarly, whenever the minimum temperature for a given day is lower than 40° F, then 40° F is used as the minimum temperature in the equation. (This method of calculating GDD was suggested to the authors by E. Arlo Richardson, Climatologist for the State of Utah.)

Appendix table 49 shows the long-term mean values for precipitation received at the town of Emery and precipitation amounts received at either the study area or the closest rain gage to the study area from January 1977 through September 1982. NOAA discontinued collection of data at Emery after April 1978. The U.S. Geological Survey maintained a recording rain gage for a short period during 1978 and 1979 about 0.25 mile (0.4 km) south of our Persayo soil study site.

On a calendar year basis, every year during the study received more precipitation than the long-term average reported for Emery. However, in arid regions plant growth is often more closely related to soil moisture accumulation during the previous cold portion of the year. For example, Hutchings and Stewart (1953) found a close correlation between herbage production on Utah's desert winter ranges and precipitation received between October 1 and September 30. Figure 20 shows the cumulative amount of precipitation received in the vicinity of Emery and, beginning in May 1979, at the Emery study area from 1978 through 1982. The first three

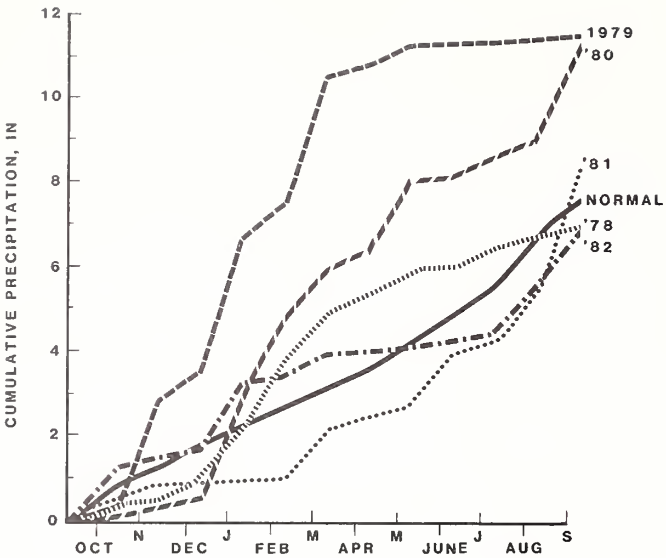

Figure 20.—Cumulative precipitation received at the Emery study area during each water year from 1978 to 1982, and for the normal water year.

growing seasons were wetter than normal, whereas the last two were drier than normal. The 1982 season did, however, receive enough overwinter precipitation (appendix table 50) to enable the cool season grasses, especially Russian wildrye, to produce moderately well.

The early growing season in the Emery area normally receives less precipitation than the last part of the growing season, July through September. Thus, plant species that respond to midsummer and late summer rainfall are favored. Plants such as galleta grass, blue grama grass, globemallow, and winterfat are quick to use summer rainfall. Even so, warm months in which only the average amount of rain falls are drought periods because of the high evapotranspiration rate in this region. Only the fortunate circumstance of one or more rainfall events of 0.4 inches (10 mm) or more in most growing seasons enables many plant species to survive and reproduce in this arid environment. In the 61 years of 1922 to 1982 an average of 3.3 such events occurred each year at Emery from May through September. The growing season of 1979 was one of only five during that period in which no rainfall events of that magnitude were recorded. So the growing season of 1979 was possibly favorable for plants that depend on winter moisture and enter a midsummer dormant period, but was an exceptionally unfavorable season for plants that depend on summer rainfall for survival or growth. Appendix figure 52 shows the probability of occurrence for a rainfall event of 0.4 inches for each month of the year.

Soil-water potential measurements, obtained from thermocouple psychrometers in 1980 and 1981, revealed some general trends. However, soil water potentials tend to vary considerably from spot to spot, creating difficulty in obtaining representative samples on large field plots.

As shown in appendix tables 51 and 52, soil moisture stress for plants (-15 bars or lower) usually became critical toward the end of June. Penoyer soil tended to reach lower water potentials earlier than Persayo soil. Castle Valley soil exhibited low water potentials at the 20-inch (51-cm) depth, possibly indicating a lack of soil water recharge at this particular site. Blue Gate shale soil material that had been severely disturbed by deep ripping usually exhibited lower water potential than nondisturbed soil. Interestingly, the shaley subsoil material rarely reached water potential levels below -10 bars.

Water potentials in gouged pits were often, but not always, higher than a nongouged location. This was especially noticeable following the heavy rains of early September 1981. Soil drying was much more severe in 1981 than in 1980. By mid-August 1981 some soils had become so dry that psychrometer readings could not be obtained.

CONCLUSIONS AND RECOMMENDATIONS

Based on data obtained over 5 years at the several sites discussed in this report, we reached the following conclusions and recommendations:

1. First-year seedling establishment of broadcast-seeded grasses and shrubs should be greater when the seeding is followed by light harrowing than when seeding is followed by cultipacking or when seeding is done with the gouger-seeder.

2. Yield of grasses and shrubs should be greater on Persayo and Penoyer soils when seeding is done with a gouger-seeder than when seeding is followed by harrowing or cultipacking. Sampling variation at Emery was too great to permit statistical confirmation of the numerical superiority of yields on gouged areas.

3. The establishment of a vigorous stand of grass on the principal study areas of Persayo and Penoyer soils on the Emery coal field was enhanced by the addition of an alfalfa hay soil amendment applied at a rate of 2.5 tons per acre (5.6 tons/ha). Although after 5 years grass yield and frequency of occurrence were not demonstrably greater on hay-amended areas than on nonamended areas, grasses remained visibly greener in color on amended soil, especially during portions of the growing season when soil moisture was at a high level.

4. On the smaller plots, where individual grass species were planted, the first-year density of grass seedlings was greater on hay-amended Persayo and Penoyer topsoils than on nonamended topsoil, but the observed difference could not be verified by statistical analyses. The addition of composted conifer tree bark to either Persayo or Penoyer soils inhibited grass seedling establishment on these same plots.

5. No consistent difference in either stand yield or average percent frequency of plants could be detected between topsoil and subsoil areas of the Persayo and Penoyer soils series.

6. Soil of the Penoyer series should support a more vigorous stand of perennial grasses than soil of the Persayo series. Of 10 species studied, only *Sitanion hystrix* exhibited better growth on Persayo soil than on Penoyer soil.

7. Indian ricegrass (*Oryzopsis hymenoides*) appears especially well adapted to soil of the Penoyer series and

should always be considered for use in revegetation programs on Penoyer soils.

8. Perennial grass and shrub establishment on topsoil of the Castle Valley soil series will be greatly superior to that on subsoil of the same series, and topsoil should be used for revegetation of reclaimed areas where the Castle Valley soil must be used.

9. Excellent results in establishing shrubs, especially chenopods, on soils of the Emery coal field can be obtained by using container-grown planting stock. Planting should be done no later than May 15, and plants should be given 1 to 2 qt (1 to 2 liters) of water at the time of planting. Additional supplemental water should only be necessary on clay soils.

10. Topsoil of the Castle Valley soil series should yield excellent shrub survival. However, growth rate of most shrubs should be better on Penoyer topsoil than on topsoils of the Castle Valley or Persayo series. Survival of well-adapted shrub species should be acceptably high on soils derived from Blue Gate shale or other shaley subsoil, but growth rate will be much slower than on topsoil materials.

11. Most species of chenopods, growing at a mean density of approximately 10 per 100 ft^2 ($0.9/m^2$), may reach nearly maximum height in the first 2 years after transplanting in the arid environment of the Emery coal field. However, diameter growth may continue to increase slowly in subsequent years.

12. Of the four soil materials on which alkali sacaton and four accessions of globemallow were established by interplanting among planted shrubs, Penoyer topsoil was superior in terms of survival and growth.

13. The following shrub species are recommended for use in reclamation of surface-mined lands of the Emery coal field:

A. On all soil materials studied—
   Fourwing saltbush
   Bonneville saltbush
   Broadscale saltbush
   Trident saltbush
   Prostrate summercypress
   Mediterranean camphorfume
   Winterfat
   Plumed whitesage

B. Species adapted mostly to sandy soils—
   Black sagebrush
   Nevada ephedra
   Fourwing saltbush X Cuneate saltbush hybrid

C. Species unsuited to sandy soils—
   Corymbed eriogonum

D. Species showing promise; further study desirable—
   Fourwing saltbush X Trident saltbush hybrid
   Fourwing saltbush X Idaho saltbush hybrid
   Bonneville saltbush X Trident saltbush hybrid

14. Utah juniper trees 3 ft (0.9 m) or less in height can be successfully lifted and transplanted with a front-end loader of the size and type used in our trial at Emery. Pinyon trees 5 ft (1.5 m) or less in height can be successfully transplanted in the same manner. Transplanting should be done in early spring to allow as long a time as possible for root regrowth to occur before soil moisture is diminished.

PART II: RESEARCH ON THE ALTON COAL FIELD

STUDY AREAS

The Alton coal field lies in Kane County, southwestern Utah, adjacent to the southern edge of the Paunsagunt Plateau. It is in the extreme northern corner of the Grand Canyon Section of the Colorado Plateau Province (Thornbury 1965). The study sites are approximately 20 miles (32 km) north-northeast of the town of Kanab and about 10 miles (16 km) southeast of the town of Alton (appendix figure 62).

Vegetation on the Alton coal field is dominated by the pinyon-juniper woodland type. Mountain brush and sagebrush communities are interspersed within the pinyon-juniper. The mountain brush areas are dominated by gambel oak (*Quercus gambelii* Nutt.), big sagebrush (*Artemisia tridentata* Nutt. var. *tridentata*), low sagebrush (*Artemisia arbuscula* Nutt.), and mountain snowberry (*Symphoricarpos oreophilus* Gray). The sagebrush type is characterized principally by big sagebrush, low sagebrush, rubber rabbitbrush (*Chrysothamnus nauseosus* [Pallas] Britt.), and antelope bitterbrush (*Purshia tridentata* [Pursh] DC). Although grasses and forbs are less important components of the vegetation of much of the Alton coal field, native species of grasses such as Indian ricegrass, blue grama, western wheatgrass (*Agropyron smithii* Rydb.), and squirreltail (*Sitanion hystrix* [Nutt.] J. G. Sm.) may be found, along with such introduced species as cheatgrass (*Bromus tectorum* L.), tall wheatgrass (*Agropyron elongatum* [Host] Beauv.), and crested wheatgrass (*Agropyron cristatum* [L.] Gaertn.). Conspicuous forbs are globemallow (*Sphaeralcea* spp.), penstemon (*Penstemon* spp.), spiderflower (*Cleome* spp.), and coyote tobacco (*Nicotiana attenuata* Torr. ex Wats.). In terms of total number of plant species present, the flora of the Alton coal field is quite rich, though many species are only occasionally found.

Soil orders identified by the U.S. Department of Agriculture, Soil Conservation Service, on the Alton coal field are Entisols, Mollisols, Aflisols, and Inceptisols (USDI 1975). The coal-bearing strata are all within the Dakota sandstone formation of Cretaceous age. Soils are variable in texture, ranging from silty clays derived from the Tropic Shale Formation, which overlies the Dakota, to sandy loams derived from the Dakota sandstone. Most surface soils exhibit near neutral to slightly alkaline soil reactions, and salinity and sodicity present no problems for plant growth. However, certain strata of subsoil material have sodium adsorption ratios and conductivity values inimical to plant growth.

The climate of the Alton study area is probably somewhat milder and slightly drier than at the town of Alton, the nearest permanent weather station. Average annual precipitation there has been 16.4 inches (417 mm). The study area is roughly 500 ft (152 m) lower in elevation than the town, and from examination of the scanty data obtained (USDI 1979) closer to the study area, the average annual precipitation there is apparently between 14 and 15 inches (356 and 381 mm). At the Alton study site, the average precipitation ranges between 1.19 and 1.49 inches (30 and 37 mm) for 7 months of the year (appendix table 65). Of the remaining 5 months, May and June are the driest, averaging about 0.7 inches (18 mm). August, December, and January receive about 1.8 inches (46 mm) per month. The long-term average for the frost-free season at Alton is 108 days.

METHODS

The Alton coal field has considerably more danger of severe soil erosion than does the Emery coal field. The average annual precipitation at Alton is more than twice that at Emery, and high intensity midsummer rain storms are more common. Because of the erosion hazard and the steeper terrain at Alton, two studies were initiated in autumn 1976 to evaluate the effects of different surface treatments and organic soil amendments on the establishment and growth of vegetation following direct seeding.

Site Preparation and Soil Amendments

We selected an 8-acre (3.24-ha) site occupied by an old-growth pinyon-juniper stand with a predominantly southeastern exposure and slopes of 5 to 20 percent. The site is in sec. 18, T40S, R4½W in Kane County, Utah, at an elevation of approximately 6,550 ft (1 996 m). All trees were bulldozed from the study area, piled, and burned (fig. 21). Using a D-8 Caterpillar tractor, an 8- to 15-inch (20- to 38- cm) layer of topsoil was removed from most of the area and stockpiled in two windrows (fig. 22).

Figure 21.—Removing a dense stand of juniper and pinyon trees prior to the initiation of research on the Alton 8-acre study area. November 1976.

Figure 22.—Stockpiling topsoil in windrows prior to deep ripping on the Alton 8-acre study area. November 1976.

The subsoil on portions of the area was then "ripped" to a depth of 30 inches (76 cm) and smoothed by blading, followed by the replacement and smoothing of the topsoil material. With the addition of a grass hay soil amendment to part of the area (fig. 23), field crews applied the following treatments (see appendix fig. 53 for field design):

1. Topsoil removed, subsoil ripped, topsoil replaced, area gouged and seeded
2. Same as 1 except that contour furrowing followed topsoil replacement rather than gouging

Figure 23.—Rotovating grass hay into the top 8 inches of topsoil after the topsoil had been replaced over ripped subsoil on the Alton 8-acre study area. November 1976.

3. Same as 1 except that grass hay was rotovated into the top 8 inches (20 cm) of soil at a rate of 2.5 tons per acre (5.6 tons/ha) and the area was not gouged prior to seeding
4. Topsoil was left in place, the area gouged and seeded
5. The original topsoil covered with stockpiled topsoil that was later removed, and the surface gouged prior to seeding

Seeding was done immediately after site preparation in late December, using hand-operated Cyclone seeders. The seed mixture used is shown in table 19. At the time of seeding the soil surface was quite rough, loose, and dry. No effort was made to cover the seed or firm the seedbed.

In September 1977, we sampled all treatments to obtain data on density, frequency, and plant height, but we made no effort to distinguish individual species of grasses or forbs. Similar data were obtained in September 1978, when it was practical to record the data by individual species. In August 1979 and July 1980, 1981, and 1982, data were obtained on all grasses, all forbs, and all shrubs (without distinguishing species), and on mean plant height and estimated yield of grasses, legumes, and shrubs.

Table 19.—Composition of seed mixture sown on the 8-acre study area, Alton coal field

Common name	Scientific name	Source	Pounds per acre
'Nordan' crested wheatgrass	*Agropyron desertorm*	South Dakota	4
Intermediate wheatgrass	*Agropyron intermedium*	South Dakota	4
'Luna' pubescent wheatgrass	*Agropyron tricophorum*	?	4
Russian wildrye	*Elymus junceus*	Montana	4
'Nomad' alfalfa	*Medicago sativa*	?	1
Yellowblossom sweetclover	*Melilotus officinalis*	Canada	1
Antelope bitterbrush	*Purshia tridentata*	Nevada	2
Fourwing saltbush	*Atriplex canescens*	Kane Co., UT	2
Winterfat	*Ceratoides lanata*	Sanpete Co., UT	0.5
Green ephedra	*Ephedra viridis*	Sanpete Co., UT	1
Cliffrose	*Cowania stansburiana*	Salt Lake Co., UT	1

Organic Amendments and Grass Species

To further determine the effects of hay and composted bark amendments on the establishment and growth of selected grass species, and to compare the response of those species when the amendment was added to both topsoil and subsoil, an additional study was made. In December 1976, two portions of the 8-acre (3.2-ha) area

described above were set aside. As on the larger portion of the area, the topsoil was removed and stockpiled, and the subsoil ripped and smoothed. The following treatments were then applied, with two replications on one portion and a third on the other portion:

1. Eight inches (20 cm) of topsoil replaced over the subsoil
2. Same as 1, plus grass hay rotovated into the topsoil at a rate of 2.5 tons per acre (5.6 tons/ha)
3. Same as 1, plus composted conifer bark rotovated into the topsoil after being spread to a depth of 1 inch (2.5 cm)
4. Subsoil rotovated to a depth of 8 inches
5. Same as 4, with grass hay rotovated into the top 8 inches of subsoil at a rate of 2.5 tons per acre
6. Same as 4, with composted bark rotovated into the top 8 inches of subsoil at the same rate as in 3

Each of the six treatments were applied to an area 15 ft wide by 100 ft long (4.6 m by 30.5 m) in each of the three replications. In turn, each such strip was divided into 10 subplots, 10 ft by 15 ft (3 m by 4.6 m), and a different species of grass sown on each subplot. The field design is shown in appendix figure 54. Seeds were broadcast by hand on the loose soil at a rate of 20 lb per acre (22.7 kg/ha). Species used and source of each, where known, are shown in table 20.

In September 1977 and 1978, we obtained data on density, frequency, and plant height. In August 1979 and July 1980, 1981, and 1982, we obtained data on frequency, plant height, and yield (weight-estimate method).

Table 20.—Grass species used on soil type–soil amendment plots at the 8–acre study area, Alton coal field

Common name	Scientific name	Source
'Fairway' crested wheatgrass	*Agropyron cristatum*	?
'Alkar' tall wheatgrass	*Agropyron elongatum*	?
'Whitmar' bluebunch wheatgrass	*Agropyron inerme*	Aberdeen, ID
Intermediate wheatgrass	*Agropyron intermedium*	?
'Sodar' streambank wheatgrass	*Agropyron riparium*	Canada
'Rosana' western wheatgrass	*Agropyron smithii*	Montana
'Luna' pubescent wheatgrass	*Agropyron tricophorum*	?
Smooth bromegrass	*Bromus inermis*	?
Basin wildrye	*Elymus cinereus*	Aberdeen, ID
Russian wildrye	*Elymus junceus*	Montana

Grass and Shrub Species

To determine the value of different species of grasses and shrubs for use in the revegetation of some of the different soil materials found on the study area, we conducted research on a 3-acre (1.2-ha) site and supplemented with a greenhouse bioassay study. The study site is less than 0.25 mile (0.4 km) east-southeast of the 8-acre (3.2-ha) site referred to above. Situated on a west-facing slope of approximately 25 percent, the site originally included a 15-ft (4.6-m) deep trench along the contour, of about 0.2 acre (0.08 ha), that exposed the top 3 to 5 ft (0.9 to 1.5 m) of a coal seam. To prepare the site for the planned research, the trench was filled and graded to the original slope of the land, using primarily the material originally taken from the trench. Then all trees were bulldozed from an area of 3 acres, with the originally trenched area in the center of the 3-acre tract. Next, starting near the top of the slope, field crews applied four soil materials as follows:

1. A 50-ft (15.2-m) strip of sandy loam topsoil was left in place, but ripped to a depth of 2 ft (0.6 m) and not releveled
2. A 50-ft wide area was stripped of approximately 1 ft (0.3 m) of topsoil and 2 ft of gravelly clay loam subsoil, leaving the silty clay subsoil exposed; this area was also ripped and the furrows thus created left in place
3. Two 25-ft (7.6-m) wide terraces were formed by removing the gravelly clay loam and silty loam subsoils down to a layer of dark-colored carbonaceous shale that lay immediately above the coal seam; depth of the carbonaceous shale layer was about 3 ft (0.9 m)
4. A 50-ft wide strip of "fill" material composed of the gravelly clay loam subsoil was taken from the area described in 2 above, and transported downhill to an area just below the terraces

On each of the four areas of different soil material, the same 12 species of grasses were seeded (broadcast by hand) on a 10- by 50-ft (3- by 15.2-m) plot, with two replications. The field design is shown in appendix figure 55. All species were seeded at a rate of 20 lb/acre 22.7 kg/ha) except for a rhizomatous type of crested wheatgrass and a hybrid of *Agropyron spicatum* and *Agropyron repens*, which were sown at a rate of 10 lb/acre (11.4 kg/ha).

Data were taken in the same manner and at the same time of year as described for the studies on the 8-acre (3.2-ha) area. Table 21 shows the grass species used and the source of seed, where known.

We did a greenhouse bioassay study using four soil materials from the 3-acre (1.2-ha) site (sandy loam topsoil, gravelly clay loam subsoil, carbonaceous shale, and a silty clay subsoil) to compare the soils as growing media for plants. A factorial experimental design was used, with four soils, four amendments, with two replications.

The soil materials were placed in plastic trays and treated as follows: (1) a 1-inch (2.5-cm) layer of composted conifer bark spread over the surface and then mixed thoroughly with the soil, (2) a 0.5-inch (1.3-cm) layer of composted bark incorporated with the soil in the same way, (3) ammonium nitrate thoroughly mixed into the soil at a rate of 100 lb N per acre (17.9 kg/ha), and (4) no amendment, to serve as a control treatment.

Bromus inermis and *Agropyron elongatum* were used as test species. Fifty seeds of each species were sown in each tray of soil material (two rows of 25 seeds of each species). We obtained data on seedling emergence and

Table 21.—Grass species sown on four different types of soil materials at the 3-acre site, Alton coal field

Common name	Scientific name	Source
'Fairway' crested wheatgrass	*Agropyron cristatum*	?
Crested wheatgrass (rhizomatous)	*Agropyron cristatum*	ARS; Logan, UT
'Alkar' tall wheatgrass	*Agropyron elongatum*	?
'Whitmar' bluebunch wheatgrass	*Agropyron inerme*	Aberdeen, ID
Intermediate wheatgrass	*Agropyron intermedium*	?
'Sodar' streambank wheatgrass	*Agropyron riparium*	Canada
'Rosana' western wheatgrass	*Agropyron smithii*	Montana
Hybrid wheatgrass	*A. spicatum* x *A. repens*	ARS; Logan, UT
'Luna' pubescent wheatgrass	*Agropyron trichophorum*	?
Smooth bromegrass	*Bromus inermis*	?
Basin wildrye	*Elymus cinereus*	Aberdeen, ID
Russian wildrye	*Elymus junceus*	Montana

plant height over a 60-day growing period. At the end of the period all plants were clipped, air-dried, and weighed.

To compare the survival and rate of growth of selected shrub species in competition with the 12 species of grass evaluated on the 3-acre site, container-grown shrubs were planted into the year-old grass plots in May 1978. Ten species of shrubs were planted in only one replication of the grass plots. A single row of each species was planted across the grass species plots on each of the four types of soil material. Shrubs were planted on a 5-ft (1.5-m) grid so that two plants of each shrub species were in each grass species plot on each soil type. Appendix table 53 lists the species of shrubs planted and their source, when known. Appendix figure 55 shows the field design. In every autumn from 1978 through 1982, we obtained data on survival and size (height and diameter) of all shrubs.

Plant Species on Soil and Overburden Types

In autumn 1976 we started a study in cooperation with Utah International, Inc., to test the possibility of establishing vegetation on a carbonaceous shale overburden material without applying a topsoil covering. Additional objectives of the study were (1) to compare the establishment and longevity of vegetation on the carbonaceous shale with that on carbonaceous shale covered with different kinds of topsoil available in the area, (2) to monitor soil moisture status throughout the growing season, and (3) to monitor the status of soil salinity.

A 0.5-acre (0.2-ha) study area in sec. 14, T40S, R5W, in Kane County, Utah, was cleared of all native vegetation and fenced to exclude rodents, livestock, and deer. On the nearly level site, two areas, each 30 ft by 83 ft (9.1 m by 25.3 m) were excavated to a depth of 40 inches (102 cm) and filled with 30 inches (76 cm) of carbonaceous shale from above the nearby coal seam. Using plywood partitions, each of the two areas was then subdivided into eight 10-ft by 30-ft (3-m by 9-m) plots. Four adjacent plots constituted one replication of the four following treatments: (1) unweathered carbonaceous shale, 40 inches (102 cm) deep; (2) 30 inches (76 cm) of the same shale, covered with 10 inches (25.4 cm) of loam topsoil; (3) 30 inches of the same shale, covered with 10 inches of sandy loam topsoil; and (4) 30 inches of the same shale covered with 10 inches of silty clay topsoil (appendix fig. 56).

After being leveled, the lower half of each of the 16 plots was fertilized with ammonium sulfate and treble super phosphate at the rate of 80 lb each of elemental N and P per acre (90 kg/ha). In November a seed mixture comprised of six species of grasses, six species of forbs, and six species of shrubs was sown by hand broadcasting and raking. Grasses and forbs were each sown at a rate of 1 lb of pure live seed per acre (1.12 kg/ha), while each shrub species was sown at a rate of 2 lb/acre (2.24 kg/ha) (except for *Ceratoides lanata*, which was sown at a 1 lb rate).

Colman fiberglass soil moisture sensors were installed at three depths—8, 18, and 30 inches (20, 46, and 76 cm)—at a single location on each plot. The sensors included a thermistor, which enabled us to also measure soil temperature. In 1977, 1978, 1979, and 1981, plant density and cover were recorded from a sample of 24 subplots, each 1 ft^2 (0.09 m^2), on each of the 16 study plots. Vegetative production was sampled in August 1979, 1980, and 1981 by clipping and weighing all grasses and forbs from one-fifth of the area of each of the 16 plots. Productivity of shrubs was estimated by the weight-estimate method (Pechanec and Pickford 1937).

Soil moisture and temperature were measured on five occasions during the growing season of 1977, and at approximately weekly intervals during the growing seasons of 1978 through 1980. Soil samples were taken in the autumns of 1978 through 1982 to determine soil salinity status.

We subjected data to analyses of variance and tests of mean separation to evaluate differences in vegetation on the four soil materials. The plant species used in the seed mixture are shown in appendix table 54.

Shrub and Forb Species

We made three plantings on the Alton study area, one in 1977 and two in 1980, to evaluate survival and growth rates of a wide variety of shrub species and several forb species. The results will aid those responsible for selecting suitable plant species for use in surface mine reclamation on the Alton coal field.

The 1977 planting was made on a disturbed core drilling site adjacent to the 8-acre (3.2-ha) study site previously described. The site was enlarged to approximately 75 by 144 ft (23 by 44 m) by the removal of several trees. Container-grown plants of 27 shrub species and three forb species were planted in individual plots of 6 ft by 15 ft (1.8 by 4.6 m). Ten plants of a given species were planted in each plot, in two rows of five plants

each, spaced 3 ft (0.9 m) apart in both directions. Each species plot was represented once in each of four blocks. Planting was done in mid-June, and each plant was given 0.5 gal (1.9 liters) of water at the time of planting. No other supplemental water was provided. We obtained data on survival and plant growth in autumn of 1977, spring and autumn 1978, and the autumns of 1979 through 1982. Appendix table 55 shows the species planted and original seed source, if known. Appendix figure 57 shows the field plot design.

On May 28, 1980, field crews planted 18 accessions of shrubs, seven herbaceous accessions, and four accessions of trees on a reconstructed soil material about 200 yards (183 m) west of the 8-acre (3.2-ha) study site. Utah International, Inc., had excavated a 50-ft (15-m) deep pit to obtain samples of the coal vein at that location, then refilled the excavation and graded the site.

All plants used had been grown in the greenhouse in plastic, Spencer-Lemaire type containers except for hybrid poplar (*Populus* spp.), which had been propagated from hardwood cuttings in 0.5-gal (1.9-liter) pots, and gambel oak (*Quercus gambelii*), which had been grown in Japanese paper pots. Planting was done in holes made with a gasoline-powered soil auger. No supplemental water was applied at the time of planting, nor at any time thereafter.

Field crews planted 15 accessions of shrubs and all of the herb accessions in a randomized block design, with four blocks. Five plants of each accession were planted in a single row in each block. Spacing was on a 4-ft (1.2-m) grid. The remaining three accessions of shrubs and the four accessions of trees were planted in the form of a windbreak. Two rows of 10 plants of each accession were planted, with 8 ft (2.4 m) between rows and a 10-ft (3-m) spacing between plants within each row.

We recorded data on plant survival and size each autumn from 1980 through 1982. Appendix table 56 lists the species used and original seed source, if known. Appendix figures 58 and 59 show the field plot design.

Also, in May 1980, field crews planted 20 accessions of fourwing saltbush east of, and adjacent to, the randomized block shrub planting. The saltbush planting was also a randomized block design, with three blocks. Each accession was planted in a separate row, five plants per row, with 20 rows per block. Plant spacing was on a 4-ft (1.2-m) grid. Appendix table 57 lists the sources of the accessions used. Appendix figure 60 shows the field plot design. We obtained data on plant survival and plant size each autumn from 1980 through 1982.

Characterization of the Microclimate

In May 1979, two battery-powered (solar-charged) automatic data loggers were installed, one at the 8-acre (3.2-ha) site and one at the Utah International site 1.9 miles (3 km) to the west. The elevation of the latter site—6,440 ft (1 963 m)—is 110 ft (34 m) lower than the 8-acre site. Ambient air temperature 54 inches (137 cm) and 12 inches (30 cm) above ground, soil temperature 2 and 8 inches (5 and 20 cm) below the surface, and cumulative precipitation received by an unheated tipping bucket rain gage were monitored at hourly intervals. In addition, thermocouple psychrometers were placed in the soil at depths of 8 and 20 inches (20 and 51 cm) at (1) three locations on each of the six treatments of one replication of the soil amendment study on the 8-acre site, and (2) three locations on each of the four soil materials on the 3-acre (1.2-ha) site. Psychrometers were read at weekly intervals from late June through October 1979. However, problems with faulty voltmeter functioning made many readings in 1979 suspect. Readings were taken at weekly intervals from July 12 through September 28, 1980, and from May 12 through September 26, 1981.

RESULTS AND DISCUSSION

Establishment of grasses and legumes by broadcast seeding on loose soil materials was successful even though no effort was made to cover the seed. However, silty clays were definitely the poorest soil materials in terms of stand establishment. The advantages of returning a good quality topsoil to the surface of the area to be revegetated was clearly demonstrated. We also found that a side variety of plant species can be used in the environment of the Alton coal field.

Site Preparation and Soil Amendments

The severe drought during autumn 1976 and the first third of 1977 prevented normal early spring germination and seedling emergence of the species seeded in December 1976. However, fair to good seedling emergence occurred on all treatments following a rainy period in the latter half of May (2.34 inches or 59 mm at the town of Alton).

At the end of the first growing season, frequency of grass plants averaged 92 percent on the ripped area where hay had been rotovated into the soil surface, compared to an average frequency of 52 percent on ripped areas receiving no hay amendment (table 22). Mean percent frequency of legumes and shrubs on the hay-amended area was 40 and 4 percent, respectively, compared to an average of 21 and 2.5 percent for legumes and shrubs on nonamended areas. Mean maximum number of grass seedlings per square foot was 12.8 ($138/m^2$) on the hay-amended area compared to 5.2 ($56/m^2$) on nonamended areas. Areas severely disturbed by topsoil removal, ripping, and topsoil replacement exhibited a mean frequency of 66 percent for grasses, compared to a mean frequency of 42 percent on areas where topsoil was left in place.

Above-average precipitation during the winter of 1977 to 1978 resulted in excellent plant growth in 1978. Smooth brome was a prominent component of the grass stand where the hay amendment had been used because it was a major component of the hay.

The total percent frequency of grasses tended to remain somewhat higher on the hay-amended area than on nonamended areas throughout the study because of the well established, rhizomatous smooth brome. With smooth brome included, the mean frequency of grasses on the hay-amended area was 97 percent in 1982. During this period, the vegetative stand density

Table 22.—Frequency (percent) and yield (lb/acre, air-dry) of plants according to treatment and year, Alton coal field

Treatment	Year	Grasses Freq.	Grasses Yield	Legumes Freq.	Legumes Yield	Shrubs Freq.	Shrubs Yield	Total yield
0 = Strips where topsoil	1977	43	—	21	—	2	—	—
was stockpiled.	1978	57	—	14	—	4	—	—
Surface gouged	1979	60	[1]1,400	16	490	2	—	[2]1,890
after	1980	63	2,168	12	662	1	0	2,830
redistribution of	1981	53	475	14	347	2	14	836
topsoil	1982	78	910	16	420	3	34	1,364
1 = Topsoil removed,	1977	52	—	21	—	3	—	—
subsoil ripped,	1978	67	—	19	—	4	—	—
topsoil replaced,	1979	71	1,325	16	430	3	—	1,755
surface gouged	1980	75	1,294	15	439	1	10	1,743
	1981	78	508	13	271	3	23	802
	1982	88	810	10	380	2	53	1,243
2 = Topsoil left in	1977	40	—	17	—	1	—	—
place, surface	1978	61	—	13	—	5	—	—
gouged	1979	70	895	10	105	4	—	1,000
	1980	73	1,079	4	160	3	23	1,262
	1981	73	580	6	127	2	12	719
	1982	82	590	6	390	6	93	1,073
3 = Topsoil removed,	1977	53	—	22	—	8	—	—
subsoil ripped,	1978	53	—	22	—	8	—	—
topsoil replaced,	1979	58	1,675	16	765	3	—	2,440
surface contour	1980	53	1,175	17	627	2	94	1,896
furrowed	1981	62	583	22	498	2	4	1,085
	1982	77	720	17	620	4	150	1,490
4 = Topsoil removed,	1977	92	—	40	—	4	—	—
subsoil ripped,	1978	[3]76	—	19	—	5	—	—
topsoil replaced,	1979	87	1,950	14	170	1	—	2,120
hay amendment	1980	89	1,637	21	517	1	2	2,156
added	1981	78	537	11	118	1	4	659
	1982	79	830	17	180	0	0	1,010

[1]Dry weight on all treatments in 1979 was estimated to be 50 percent of green weight.
[2]Smooth brome constituted 31, 35, 36, and 45 percent of the total yield in 1979, 1980, 1981, and 1982, respectively.
[3]Percent frequency shown for treatment 4 is exclusive of the smooth brome component, except in 1977.

appeared to reach essentially similar status on the rest of the study area.

The legume component of the established vegetation contained many vigorous yellow sweetclover plants in the second growing season. However, few remained by 1979, and sweetclover was rarely encountered in subsequent years. Alfalfa became the primary seeded legume, and despite an apparent steady decrease in percent frequency during the 6 years, many vigorous plants remain in the stand (fig. 24).

The most prominent shrub species in the first growing season were fourwing saltbush, winterfat, and bitterbrush, in that order. Cliffrose and green ephedra seedlings were only occasionally encountered. During the subsequent 5 years, overall percent frequency of shrubs remained relatively constant (table 22). Winterfat decreased drastically in numbers. But bitterbrush and cliffrose became much more conspicuous and productive. After 6 years, many excellent fourwing saltbush shrubs remained (fig. 25), but green ephedra was extremely rare.

Table 22 also shows mean estimated yields of grasses, legumes, and shrubs, beginning with the third growing season for grasses and legumes and the fourth season for shrubs. The severely disturbed area, where a hay amendment was added to the soil, yielded slightly more

Figure 24.—Vigorous plants of 'Nomad' alfalfa intermixed with a good stand of perennial grasses in the sixth year following seeding on the Alton 8-acre study area. July 15, 1982.

Figure 25.—Excellent Atriplex canescens *shrub established by seeding in autumn 1976 on the Alton 8-acre study area. July 1982.*

Figure 26.—A broadcast-seeded mixture of perennial grasses and alfalfa, in the year of peak production (fourth growing season) on the Alton 8-acre study area. July 17, 1980.

vegetative growth in 1979 than similarly disturbed areas that were not amended. In subsequent years the other treated areas yielded equally as well as the hay-amended area. In fact, the establishment of smooth brome on the hay-amended area may have resulted in lower overall yield, as this species has not been especially vigorous on the study area despite occupying considerable space and competing successfully with the four seeded grasses.

The two narrow strips across the study area on which topsoil had been stockpiled sustained a more vigorous growth of grasses throughout the study period than did most of the other treated areas, even though the percent frequency of grasses was low. Coupled with high yields by alfalfa, the excellent yield of vigorous grass plants resulted in much higher total yield than occurred on the other areas where topsoil was left in place. A possible explanation of this is that not as much topsoil was removed during redistribution to the rest of the area as was added to the strips during stockpiling. The increased depth of topsoil may thus have created improved growing conditions.

Yield of the mixed grass and alfalfa stand seemed to "peak" in the third and fourth growing season (fig. 26). Rumbaugh and others (1982) found that in mixed plantings of crested wheatgrass, fourwing saltbush, and alfalfa, the crested wheatgrass was stimulated to yield more than when it grew alone; total vegetative production from the mixture was greater than from pure stands of crested wheatgrass. In our study, after 6 years yield appeared somewhat greater on those portions of the 8-acre (3.2-ha) area where a good mixed stand of alfalfa and grass occurred (fig. 27).

Legume yields fluctuated from year to year, with 1981 being particularly good for alfalfa growth. After 6 years, alfalfa still contributed a significant portion of overall forage yield.

Shrub yields, first sampled in 1980, gradually increased on all treatments except the hay-amended area, where few shrubs were able to survive in competition with the dense grass stand established in the first growing season. Bitterbrush and cliffrose were growing vigorously on the study area in 1982 (fig. 28), especially where grass competition was not severe. Numerous vigorous fourwing saltbush plants were still present. These shrub species should continue to increase in yield for several more years.

Figure 27.—View of the Alton 8-acre study area in the sixth growing season. A portion of the area where a grass hay soil amendment was used is visible in the left-center. Dense growth of Bromus inermis *in this portion of the area severely limited establishment of alfalfa, numerous plants of which are visible on the remaining area. July 15, 1982.*

Figure 28.—Good Cowania stansburiana *plants, in the sixth growing season on the Alton 8-acre study area. Cliffrose, antelope bitterbrush, and fourwing saltbush successfully competed with perennial grasses and alfalfa, although limited mostly to spots where herbaceous plants were least dense. July 15, 1982.*

Of the four grass species sown in 1976, all proved well adapted to the environmental conditions of the study area. No data were taken on species composition, but after 6 years "Nordan" crested wheatgrass remained the most common species. Intermediate wheatgrass and pubescent wheatgrass made up a significant portion of the grass stand, while Russian wildrye constituted a much smaller proportion of the stand.

In the reclamation of surface mined lands, the absolute volume of vegetation produced each year should not be a land manager's highest concern. Of greater concern is that sufficient established vegetation be maintained to preserve the soil. Total amount of vegetative growth will vary with annual growing conditions. Dense stands of grass are seldom found on the Alton coal field. Instead, the pinyon-juniper forest predominates, with interspersed areas dominated by shrubs. Establishment of a good stand of several adapted grass species, as soon as the land is restored to the desired relief, is the best way to stabilize the reconstructed soil material. The addition of forbs (especially legumes) and shrubs to the vegetative composition is desirable for a number of reasons that won't be dwelt upon here.

Although the initially established vegetation on a reclaimed area may decrease in terms of herbage yield and ground cover, the large amount of organic matter added to the soil will greatly improve the soil's fertility and physical properties. Ultimately, the land manager and researcher desire to learn the potential of the reclaimed area for supporting a particular type and quantity of vegetation. Only long-term study can give the answers.

On the 8-acre (3.2-ha), 3-acre (1.2-ha), and Utah International cooperative study sites, total plant yield diminished in the fifth and sixth year of study, yet on most areas soil cover remained entirely adequate to protect the soil from erosion.

Organic Amendments and Grass Species

As on the larger portion of the 8-acre (3.2-ha) study area, seedling emergence of grasses on individual species plots did not occur until late May 1977. At the end of the first growing season, surviving plants were most numerous on the hay-amended plots and fewest on compost-amended plots, though differences were not great. Data on mean percent frequency followed the same trend as the data on plant density. During the next 5 years, differences in percent frequency between amendment treatments were small (table 23). Mean percent frequency declined on subsoil plots and remained nearly the same on topsoil plots.

Table 23.—Mean combined percent frequency of 10 grass species by soil type and soil amendment treatment, Alton coal field

Year	Topsoil hay[1]	Topsoil compost	Topsoil control	Subsoil hay	Subsoil compost	Subsoil control
1977	43	39	40	43	34	39
1978	75	77	73	76	71	75
1979	78	80	79	71	58	71
1980	76	75	77	68	54	62
1981	70	79	79	65	59	63
1982	71	78	74	61	56	58

[1]Percent frequency on hay-amended plots does not include the smooth brome component except in 1977.

Data on yield were first obtained in the third growing season, 1979, and are shown in table 24. Yields were significantly higher on topsoil plots than on subsoil plots in 1979 and 1980 (fig. 29). No statistical analyses were made in 1981 and 1982, but yields remained considerably higher on topsoil plots than on subsoil plots through the sixth year.

Figure 29a.—Growth of perennial grasses on an area where topsoil was replaced following topsoil removal and deep ripping of the subsoil.

Figure 29b.—Growth of perennial grasses on an area where topsoil was not replaced. July 15, 1982.

No differences in yield between soil amendment treatments were found in 1979 or 1980. In 1981 and 1982, yield differences between amendments were small on topsoil plots. However, yields on hay-amended subsoil plots did appear appreciably higher than yields on compost-amended and control subsoil plots (fig. 30 and table 24).

Figure 30.—Comparison of perennial grass growth on an area of subsoil material that was amended with hay (center) and on an area of subsoil that was not amended (left). May 1979.

Table 24.—Mean combined yields (lb/acre, air-dry) of 10 species of grasses by soil type and soil amendment treatment, Alton coal field

Year	Topsoil hay[1]	Topsoil compost	Topsoil control	Subsoil hay	Subsoil compost	Subsoil control
1979	916	928	792	655	344	274
1980	1,068	904	854	478	415	407
1981	490	476	501	311	234	220
1982	973	979	866	807	513	472

[1]Yields on hay-amended plots include the smooth brome component.

Soil samples collected at the end of the sixth growing season indicated little difference in the physical and chemical properties of soil amended with hay or composted bark, and nonamended soil (appendix table 58). Topsoil did exhibit a higher saturation percentage and a higher cation exchange capacity than subsoil.

Overall, the several perennial grass species were better distributed on the topsoiled area than on the subsoil area (table 23).

The value of organic soil amendment may depend on the quality of the soil material available for use as surface soil. In this study, a grass hay soil amendment tended to increase productivity of grasses when applied to subsoil, but not when applied to topsoil.

Performance of Grass Species

On the individual grass species plots, streambank wheatgrass and crested wheatgrass were highest in percent frequency and density at the end of the first year (table 25). During the subsequent 5 years, all species except smooth brome showed some decrease in percent frequency of occurrence.

Table 25.—Mean percent frequency of 10 grass species on 10-ft by 15-ft plots in each year, 1977 through 1982, Alton coal field

Species symbol[1]	1977	1978	1979	1980	1981	1982
AGCR	[2]91(5.8)	91	92	84	72	81
AGEL	81(4.5)	86	78	71	66	64
AGIN	77(4.4)	69	72	67	57	57
AGIN[2]	89(4.8)	86	82	77	78	78
AGRI	93(6.0)	85	87	80	78	79
AGSM	57(3.2)	41	50	54	59	52
AGTR[2]	86(4.1)	70	77	74	76	76
BRIN	82(4.5)	80	82	84	94	97
ELCI	50(3.1)	35	28	25	36	25
ELJU	82(5.0)	84	77	74	68	54
Mean	78	73	72	69	68	66

[1]See appendix table 69 for plant symbol key.
[2]Values in parentheses show mean density in number of plants per square foot.

By the third year, when yield was first sampled, five of the six "introduced" species produced more herbage than any of the four "native" species (table 26). Only the introduced Russian wildrye exhibited a mean yield as low as the native species.

Table 26.—Mean yield (lb/acre, air-dry) of 10 grass species, on 10-ft by 15-ft plots, in each year from 1979 through 1982, Alton coal field

Species symbol[1]	1979	1980	1981	1982
AGCR	815	882	357	471
AGEL	932	727	653	849
AGIN	360	641	233	715
AGIN[2]	980	791	298	530
AGRI	425	541	209	320
AGSM	172	243	110	152
AGTR[2]	678	624	359	536
BRIN	680	698	271	586
ELCI	470	558	756	1,927
ELJU	360	454	172	203
Mean	587	616	342	629

[1]See appendix table 69 for plant symbol key.

Yield of most species peaked in the fourth year, 1980, which was a good growing season because of excellent overwinter soil moisture storage. That year, one of the native species, beardless bluebunch wheatgrass, approached the yield of the introduced species. However, crested wheatgrass, intermediate wheatgrass, and tall wheatgrass were still the leading herbage producers.

In the fifth year, 1981, six of the 10 grass species showed a mean decrease in yield of just over 60 percent from the previous year. The 1981 growing season was a poor one in the Alton vicinity. The only species to show an increase in yield was Great Basin wildrye, individual plants of which continued to increase in size.

By the sixth year, beardless bluebunch wheatgrass and Great Basin wildrye (native species) were two of the top three species in terms of yield. The best yielding introduced species was tall wheatgrass.

The larger sized bunchgrasses (Great Basin wildrye, tall wheatgrass, and beardless bluebunch wheatgrass) were the highest yielding species after 6 years despite being tenth, sixth, and seventh, respectively, in mean percent frequency of occurrence. Of the five rhizomatous species, three (smooth brome, pubescent wheatgrass, and intermediate wheatgrass) were intermediate in yield, along with crested wheatgrass. By 1982 the continual increase in the spread of smooth brome elevated it to first place in percent frequency. However, this species was only fourth in yield after 6 years. The other two rhizomatous species, streambank wheatgrass and western wheatgrass, ranked third lowest and lowest, respectively. Sodar streambank wheatgrass, normally a sod former, tended to resemble a bunchgrass on these plots. Western wheatgrass has not spread well on this site. The remaining bunchgrass, Russian wildrye, exhibited low yields but remains in reasonably healthy condition.

Adaptability of Grass Species

As on the other study sites on the Alton coal field, generally good seedling emergence of seeded grasses occurred in May 1977 on the 3-acre (1.2-ha) site. By the end of the first growing season, plant growth was best on plots where topsoil had been left in place, followed by the plots of gravelly clay loam subsoil, carbonaceous shale, and silty clay subsoil, in that order. Plant density and mean percent frequency were highest on plots of gravelly clay subsoil. During the next 5 years, mean percent frequency of the 12 grass species increased on all soil materials except the silty clay subsoil (table 27).

Table 27.—Combined mean percent frequency of all grass species on four different soil materials, Alton coal field

Year	Sandy loam topsoil	Gravelly clay loam subsoil	Carbonaceous shale overburden	Silty clay subsoil
1977	55	59	43	48
1978	62	60	44	34
1979	73	64	40	18
1980	77	62	44	30
1981	73	65	54	40
1982	73	63	55	41

However, there was no change on the sandy loam topsoil plots and clay loam subsoil plots after the third year.

Combined mean yields of the 12 grasses on the four soil materials fluctuated from year to year with seasonal growing conditions (table 28). However, yields on the topsoil and clay loam subsoil remained much superior to those on carbonaceous shale overburden and silty clay subsoil, as would be expected from the wide differences in stand density. After 6 years, overall yield and plant size was slightly greater on the clay loam subsoil plots than on sandy loam topsoil.

Table 28.—Combined mean yield (lb/acre, air-dry) of 12 grass species on four soil materials, Alton coal field

Year	Sandy loam topsoil	Gravelly clay loam subsoil	Carbonaceous shale overburden	Silty clay subsoil
1979	1,295	1,135	410	55
1980	677	660	356	134
1981	570	719	247	163
1982	952	1,161	638	388

Table 29 shows mean percent frequency and mean yield of each grass species sown on the study site for each year of the study. Intermediate wheatgrass, tall wheatgrass, and pubescent wheatgrass were definitely superior in herbage production during the first 3 years, although most species appeared reasonably well adapted to the sandy loam topsoil and clay loam subsoil. In the initial year, Great Basin wildrye, western wheatgrass, and the rhizomatous form of crested wheatgrass produced the thinnest stands.

As was the case on the 8-acre (3.2-ha) study site, during the first 3 years, introduced species (except Russian wildrye) produced much more herbage than native species, with the exception of Great Basin wildrye.

With the passage of time, all four of the native species improved, either in terms of frequency of occurrence or in herbage yield. Great Basin wildrye, because of its large stature, became the highest yielding species by the fifth year, and by the sixth year only tall wheatgrass, among introduced species, outyielded the native beardless bluebunch wheatgrass.

Three bunchgrasses—crested wheatgrass, tall wheatgrass, and Russian wildrye—decreased in frequency of occurrence over the 6 years. On the other hand, four of the highly rhizomatous species significantly increased in frequency (table 29). After 6 years, none of the 12 species seemed in any danger of dying out.

One reason for low yields exhibited by western wheatgrass may be the preference seemingly shown for it by the few rabbits that found their way under the exclosure fence. Rabbit use of western wheatgrass was especially noticeable during the 1981 growing season.

Bioassay of Four Soil Materials

In a bioassay study, the four soil materials on which individual grass species were tested (sandy loam topsoil, clay loam subsoil, silty clay subsoil, and carbonaceous shale overburden) were compared as growing media. No significant difference in the seedling emergence of either tall wheatgrass or smooth brome could be demonstrated between the four types of soil material. Overall seedling emergence was 98 percent for tall wheatgrass and 67 percent for smooth brome.

Analyses of variance and mean separation tests yielded evidence at the 0.05 percent level that plants grown on the four soil materials differed in leaf height after growing 60 days (table 30). Smooth brome was significantly larger when grown on sandy loam topsoil than when grown on any of the other three soils. Tall wheatgrass reached significantly larger size on sandy loam topsoil than on any other soil, and was also larger on carbonaceous shale overburden than on clay loam or silty clay subsoils.

There was no significant difference in growth (as indicated by leaf height) of either species resulting from the addition of composted conifer bark or ammonium nitrate fertilizer.

Table 29.—Mean percent frequency (Fr.) and mean yield (Yld.) (lb/acre, air-dry) of 12 species of grass grown on four soil materials, Alton coal field

Species	1977	1978	1979		1980		1981		1982	
symbol[1]	Fr.	Fr.	Fr.	Yld.[2]	Fr.	Yld.	Fr.	Yld.	Fr.	Yld.
AGCR	68	66	55	675	54	402	58	351	48	520
AGCR(r)	37	48	45	480	43	337	36	309	34	520
AGEL	56	58	52	1,610	58	1,071	56	722	49	1,730
AGIN	45	52	50	44	43	279	42	332	46	1,230
AGIN[2]	66	48	62	1,820	66	704	80	402	82	660
AGRI	57	64	54	490	58	338	68	343	69	470
AGSM	36	41	45	310	63	203	82	212	86	310
AGSP x AGRE	54	42	41	565	40	248	49	390	46	650
AGTR[2]	58	51	50	1,005	64	380	70	323	84	640
BRIN	64	69	61	540	73	697	85	397	88	640
ELCI	20	19	30	750	34	618	28	1,047	32	1,590
ELJU	53	41	49	230	44	204	49	265	34	450
Mean	51	50	50	743	53	457	59	424	58	784

[1]See appendix table 69 for plant symbol key.
[2]Yield was first sampled in 1979.

Table 30.—Mean leaf height[1] (inches) of two grass species grown in the greenhouse on four soil materials from the Alton 3-acre study site

Species	Sandy loam topsoil	Carbonaceous shale overburden	Clay loam subsoil	Silty clay subsoil
Tall wheatgrass	8.2	4.9	3.5	3.4
Smooth brome	5.9	2.5	1.8	1.5

[1]Means underscored by the same line are not significantly different at the 0.05 percent level.

The soils occurring on the 8-acre (3.2-ha) and 3-acre (1.2-ha) study sites were relatively similar in terms of salinity and sodicity (appendix tables 58 and 59). If soil materials of greater salinity or sodicity are encountered in future revegetation efforts on the Alton coal field, greater attention will be necessary to differences in salt tolerance among plant species. Moxley and others (1978) found that 'Jose' tall wheatgrass and 'Critana' thickspike wheatgrass were somewhat more salt tolerant as seedlings than either of three certified varieties of western wheatgrass—'Rosana,' 'Arriba,' or 'Barton.' However, yield of all five decreased rapidly as electrical conductivity of the soil solution increased beyond 4 mmhos/cm.

Establishment and Longevity of Plant Species

Chemical and physical analyses (appendix table 59) showed that other than being low in available nitrogen, none of the three topsoils or the carbonaceous shale overburden in this study were unsuited to plant growth. The carbonaceous shale overburden, taken from immediately above a coal seam, was observed to weather quite rapidly to a clay loam texture. Throughout this report it will be referred to as a clay loam. In the first growing season, 1977, Indian ricegrass and crested wheatgrass were the most vigorous of the six grass species on all soils. Several plants of these two species produced seed in 1977.

'Drylander' alfalfa (*Medicago media*) was by far the outstanding plant species on all soils with respect to numbers of seedlings emerging and first season growth. Some plants reached 15 inches (38 cm) in height in 1977, and numerous plants produced seed. Of the other five forb species sown, some vigorous plants of small burnet, gooseberryleaf globemallow, and cicer milkvetch became established. Although arrowleaf balsamroot and Utah sweetvetch seedlings were observed on all study plots in both 1977 and 1978, no balsamroot and only a small number of sweetvetch plants survived.

Fourwing saltbush and winterfat were the only shrub species to survive past the first two seasons. Seedlings of mountain-mahogany, bitterbrush, and green ephedra were evident in June 1978 on all plots, but none survived.

After 5 years, crested wheatgrass remained the dominant grass species on all soils. Western wheatgrass increased in density, but tall wheatgrass density decreased on all soils.

Tables 31 and 32 show the mean number of plants per square yard and the mean percent ground cover at intervals between 1978 and 1981. Number of grasses and shrubs declined on all four soil materials between 1978 and 1981. Number of forbs declined on all soil materials except silty clay, where alfalfa numbers increased. Thus, after 5 years, the decrease in plant numbers on plots of clay loam (shale overburden), sandy loam topsoil over clay loam, and loam topsoil over clay loam resulted in similar total plant density (table 31). Although plant density on plots of silty clay topsoil placed over clay loam was less than on the other soil materials (table 31),

Table 31.—Comparison of mean number of plants per square meter[1] after 2, 3, and 5 years on four soil material combinations; data pooled from fertilized and nonfertilized plots

Species	Clay loam (40")			Three topsoils (10") over 30" clay loam: Sandy loam			Loam			Silty clay		
symbol[2]	1978	1979	1981	1978	1979	1981	1978	1979	1981	1978	1979	1981
AGCR	20.7	14.6	11.4	27.0	24.9	19.8	21.9	17.6	13.4	6.8	3.8	4.8
AGEL	3.9	2.6	1.0	4.7	3.4	1.0	6.1	6.4	2.0	.9	1.1	.8
AGSM	1.0	.4	1.6	.7	1.1	3.0	2.9	2.6	8.1	.9	.2	1.1
ELJU	4.4	1.5	.8	5.2	1.3	.8	5.0	2.6	1.8	1.6	1.8	.9
ORHY	.6	—	—	.1	.1	—	.4	—	—	.6	—	—
Total	30.6	19.1	14.8	37.7	30.8	24.6	36.3	29.2	25.3	10.8	6.9	7.6
MEME	17.7	17.4	17.6	10.8	11.8	10.2	8.9	10.3	9.4	5.9	10.6	14.7
SAMI	5.8	3.0	.1	4.2	1.0	.1	3.3	2.0	.1	2.0	1.6	.6
ASCI	6.1	1.2	.2	1.8	.1	—	1.6	.3	—	1.7	.8	.3
SPGR	.4	—	.1	.2	.1	—	.3	—	—	—	—	—
Total	30.0	21.6	18.0	17.0	13.0	10.3	14.1	12.6	9.5	9.6	13.0	15.6
ATCA	1.2	.9	.7	.8	.4	—	.6	.2	—	1.5	.8	.7
CELA	3.1	.6	.1	5.4	.1	—	1.3	.1	—	1.5	.6	—
Total	4.3	1.5	.8	6.2	.5	—	1.9	.3	—	3.0	1.4	.7
Total	64.9	42.2	33.6	60.9	44.3	34.9	52.3	42.1	34.8	23.4	21.3	23.9

[1]Values shown for individual species are means of four replications.
[2]See appendix table 69 for plant symbol key.

Table 32.—Mean percent ground cover by plant class on four soil material combinations after 1, 2, 3, and 5 years. Data are pooled from fertilized and nonfertilized plots

Plant class		Clay loam (40″)	Three topsoils (10″ over 30″ clay loam)		
			Sandy loam	Loam	Silty clay
Grasses	1977	0.7	0.3	0.1	0.1
	1978	6.7	8.8	19.3	2.0
	1979	17.2	27.1	34.0	7.6
	1981	11.0	24.7	24.2	5.7
Forbs	1977	2.9	9.4	1.6	2.2
	1978	16.0	31.8	13.6	17.0
	1979	32.2	32.8	20.5	40.0
	1981	13.2	8.3	5.0	13.4
Shrubs	1977	1.2	1.3	.1	.1
	1978	6.2	6.1	1.0	3.9
	1979	9.5	6.0	1.2	4.0
	1981	1.9	.3	.2	2.2
Total cover[1]	1977	4.8	11.0	1.8	2.4
	1978	28.9	46.7	33.0	22.9
	1979	58.9	65.9	55.6	51.6
	1981	26.0	33.4	29.6	21.2

[1]Total cover shown is slightly more than true percent ground cover because of overlap among plants. Values shown in the table are means of four replications.

statistical analyses indicated the difference was only significant on the nonfertilized half of the study plots (fig. 31).

After 5 years total plant density had decreased on all soil materials except the silty clay plots, on which the number of alfalfa plants had increased. Percent ground cover had also decreased to roughly half of what it had been after the first 3 years (table 32).

Yields of all classes of vegetation declined between 1979 and 1981. Total yield in 1981 ranged from 29 percent of the 1980 yield on silty clay plots to 37 percent of the 1980 yield on loam plots (table 33).

Figure 31a.—Fertilized portion of plot of carbonaceous shale overburden covered by 10 inches of sandy loam topsoil in the sixth year following seeding.

Figure 31b.—Fertilized portion of plot of carbonaceous shale overburden covered by 10 inches of silty clay topsoil in the sixth year following seeding.

Table 33.—Mean herbage yield (grams/m^2 air-dry) on fertilized (F) and nonfertilized (NF) plots of four soil material combinations, for third, fourth, and fifth years, Alton coal field

Vegetation class	Clay loam (40")		Three topsoils (10") over 30" clay loam: Sandy loam		Loam		Silty clay	
	F	NF	F	NF	F	NF	F	NF
1979								
Grasses	228	29	224	141	251	250	101	8
Forbs	80	253	148	338	100	190	132	338
Shrubs	28	51	15	44	7	4	6	10
Total	336	333	387	523	358	444	239	356
1980								
Grasses	160	22	267	227	293	255	132	4
Forbs	208	282	277	225	107	134	222	238
Shrubs	4	5	0	4	0	4	3	12
Total	372	309	553	456	400	393	357	255
1981								
Grasses	84	15	125	104	156	96	56	2
Forbs	61	60	43	30	21	22	53	68
Shrubs[1]	—	—	—	—	—	—	—	—
Total	145	75	168	134	177	118	109	70

[1]Shrubs contributed so little yield in 1981 that they were not sampled.

Figure 32 shows the results of tests for significant differences between means, for plant numbers (density), percent ground cover, and herbage yield. The primary reason for the large decrease in total yield between 1980 and 1981 was the drastic reduction in yield of alfalfa, an average of 80 percent reduction for all soils. While no data were taken from these plots in 1982, we observed that alfalfa continued to decline in vigor and most likely in number of surviving plants. Subjective evaluation of the appearance of vegetation on these plots at that time pointed to a slight overall superiority in color and vigor of vegetation on plots of sandy loam topsoil underlain by clay loam (carbonaceous shale overburden).

Appendix tables 59 and 60 show some chemical and physical properties of each of the four soil materials used in this phase of the research at Alton. Over 6 years the salinity of all four soil materials declined (table 34). Sodicity, as indicated by the sodium adsorption ratio (SAR), steadily decreased on plots of silty clay and remained low on the other three soil materials. Even in the upper portion of the carbonaceous shale overburden (clay loam) that was covered with sandy loam, loam, or silty clay topsoil, the SAR remained low. Changes in soil properties can be expected with the passage of time. For example, some of the soil properties shown in appendix tables 59 and 60 for the carbonaceous shale soil

	Fertilized plots				Nonfertilized plots			
Total No.	17.6(L)	17.2(CL)	16.9(SL)	14.5(SC)	18.1(SL)	17.4(L)	15.6(CL)	8.8(SC)
No. grasses	13.2(L)	12.7(SL)	8.4(CL)	6.4(SC)	12.2(L)	12.0(SL)	6.3(CL)	1.2(SC)
No. forbs	8.8(CL)	8.1(SC)	4.4(L)	4.2(SL)	9.3(CL)	7.6(SC)	6.1(SL)	5.2(L)
Total cover	34(SL)	30(L)	26(CL)	18(SC)	32(SL)	30(L)	22(CL)	20(SC)
Grass cover	26(SL)	26(L)	16(CL)	10(SC)	24(L)	24(SL)	6(CL)	2(SC)
Forb cover	10(CL)	8(SC)	8(SL)	4(L)	18(SC)	16(CL)	8(SL)	6(L)
Total yield	177(L)	168(SL)	145(CL)	108(SC)	134(SL)	119(L)	75(CL)	70(SC)
Grass yield	156(L)	125(SL)	84(CL)	56(SC)	104(SL)	96(L)	15(CL)	2(SC)
Forb yield	61(CL)	52(SC)	43(SL)	21(L)	68(SC)	60(CL)	30(SL)	23(L)

Figure 32.—Results of Duncan's multiple range tests (P = 0.05) on mean values of plant numbers (no./m^2), percent ground cover, and herbage yield (g/m^2), on plots of four different soil materials after 5 years, Alton coal field. Mean separation tests were not made on total plant numbers on fertilized plots, total cover on nonfertilized plots, or forb cover on nonfertilized plots. Analyses of variance tests showed no significant differences in those sets of data. Means underlined are not significantly different. SL = sandy loam, L = loam, CL = clay loam, and SC = silty clay.

Table 34.—Electrical conductivity (ECe, mmhos/cm) and sodium adsorption ratio (SAR) of soil materials on the Utah International cooperative study site,[1] Alton coal field

	Soil material							
	Clay loam		Sandy loam		Loam		Silty clay	
Year	ECe	SAR	ECe	SAR	ECe	SAR	ECe	SAR
1976	3.3	0.5	0.6	0.8	1.1	0.6	0.6	3.1
1978	7.8	1.0	2.3	1.0	1.7	1.0	1.0	2.0
1979	3.0	.4	.5	.7	.8	.4	.5	.7
1980	1.1	.3	.3	.7	.4	.7	.3	.6
1981	.4	.7	.5	.5	.5	.6	.3	.8
1982	.9	.3	.4	.3	.4	.6	.4	.4

[1]Data are for composite soil samples from the 4– to 8–inch depth.

materials are different despite the samples being taken from the same strata of shale, at the same location. However, the results of analyses shown in appendix table 59 were from samples taken from the shale immediately after it was uncovered by the bulldozer, whereas the results shown in appendix table 60 were obtained from the surface 8 inches (20 cm) of the shale after being exposed to weathering for 6 years.

The soil moisture status on all plots of the four soil materials was monitored throughout most of each of the first four growing seasons. Throughout these four growing seasons, vegetation on the study plots exhibited little moisture stress except for brief periods during August and September. Two factors may have been responsible for this: (1) overwinter precipitation was above average every year, after the dry winter of 1976 to 1977; and (2) the 30 inches (76 cm) of carbonaceous shale used as a foundation for the soil material combinations retained soil moisture well. Soil moisture data showed that summer rains rarely replenished the soil moisture content of any soil material to a depth of 8 inches.

Color and textural differences of the four soil materials had only a small effect on soil temperatures at the 8-inch (20-cm) depth. Temperature of the reddish-colored, sandy loam topsoil was often higher during sunny weather than the temperature of the other three soils. Since sandy soils dry more rapidly than other soils, it would be expected that temperatures in sandy loam would fluctuate more rapidly than temperatures in heavier textured soils.

Soil temperatures at depths of 18 inches (46 cm) and 30 inches (76 cm) were remarkably similar during the 4 years of observation. Figure 33 illustrates the course of soil temperature at depths of 8, 18, and 30 inches throughout the growing season.

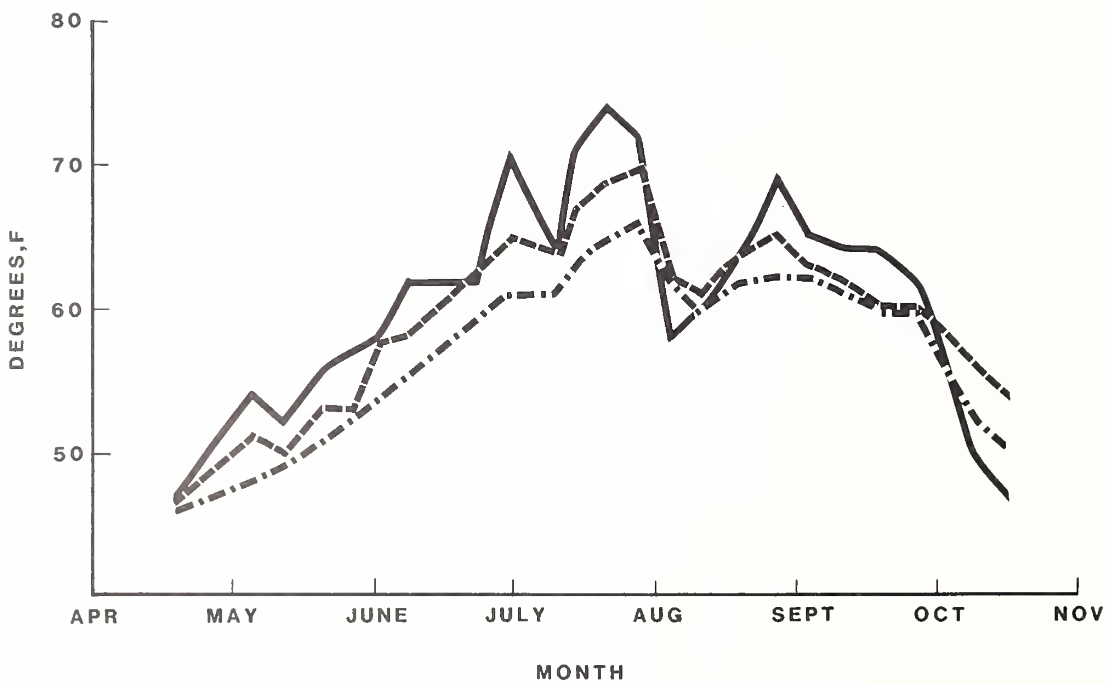

Figure 33.—At the Utah International cooperative study site, soil temperature at 8, 18, and 30 inches depth in loam topsoil (10 inches) placed over carbonaceous shale overburden during growing season of 1979.

Adaptability of Shrub and Forb Species

Of the 28 shrub and forb species planted on the drill pad site, adjacent to the 8-acre (3.2-ha) study site, 22 exhibited 90 percent or greater first-year survival. Table 35 shows the mean percent survival and mean height and diameter of all the species planted on the drill pad site after 6 years.

Most species exhibited good survival. *Astragalus globiceps*, from Turkey, gradually died out over the first 4 years. The only other species to fail completely was the accession of fourwing saltbush from New Mexico. Of the fourwing saltbush plants 98 percent survived the first season and grew to an average height of 15 inches (38 cm). However, many of the plants were in poor condition in spring 1978, and by spring 1979 only two of the original 40 plants were alive. All were dead by the end of the fourth year. Because nearly all mortality of

Table 35.—Mean percent survival and mean height and diameter of shrub and forb species 6 years after planting at the 8-acre study site, Alton coal field

Species symbol[1]	Mean survival	Mean height	Mean crown diameter
	Percent	---------*Inches*	---------
AMFR	79	9*	12
AMUT	80	24*	24
ARNO	85	15*	20
ARTR	85	26*	36
ASGL**	0	—	—
ATCA	[2]90	5	4
BEFR	90	17	17
CAAR	72	28*	31
CECU	95	24	31
CELA	50	14*	15
CELE	90	27	25
CEMO	95	26	25
CHNA	90	31*	37
COST	90	27*	29
CUAR	60	44	28
ELAN	92	47	44
EPVI	100	20*	19
HEBO**	88	22*	24
KOPR	92	24*	19
LOTA	90	22*	22
PERA	58	17	17
POFR	55	16*	16
PRVI	98	34*	25
PUTR	95	23*	30
RHTR	98	25*	33
RIAU	95	38*	37
ROWO	100	30*	34
SACE	68	18	19
SHRO	15	16	16
SPGR**	18	4*	8

[1]See appendix table 69 for plant symbol key.
[2]All original ATCA died. A different accession was planted in 1981.
*These species produced some seed in 1 or more years.
**Forbs.

fourwing saltbush occurred during the winter (minimum temperature in January 1979 reached −22° F, or −30° C), this accession apparently lacked winter hardiness. In 1981, an accession of fourwing saltbush from Johnson Canyon, 17 miles (27 km) south of the study area, was used to replace the original planting.

Many of the species produced seed one or more times during the first 6 years (table 35). Wild rose exhibited good vegetative reproduction, with some root suckers emerging up to 9 ft (2.7 m) away from the parent plant. Prostrate summercypress produced numerous seedlings, many of which became established at distances of 6 to 10 ft (1.8 to 3 m) from parent plants. Piute cypress suffered some degree of winter damage from cold temperatures nearly every winter, yet several plants continued to make excellent growth, with a maximum height of 73 inches (185 cm). Gooseberryleaf globemallow exhibited excellent vigor for the first 3 years, then declined in numbers and vigor through the sixth year.

In addition to damage from winter temperatures, several species exhibited some dieback from late spring or summer frosts. Most susceptible to frost damage was the succulent growth of elderberry, Siberian peashrub, Fremont barberry, rose, skunkbush, Tatarian honeysuckle, milkvetch, globemallow, and Piute cypress. Tent caterpillars caused severe defoliation of chokecherry in 1981, and lesser damage to rose, bitterbrush, and curlleaf cercocarpus.

After 6 years, shrubs on this site were competing quite severely with one another for space and soil moisture because of the original plant spacing of 3 by 3 ft (0.9 by 0.9 m). Several of the most vigorous species are shown in figures 34 through 39.

Figure 34.—Six-year-old Rosa woodsii, *established from container-grown planting stock on the Alton 8-acre study area. September 1982.*

Figure 35.—Six-year-old Rhus trilobata, *established from container-grown planting stock on the Alton 8-acre study area. September 1982.*

Figure 36.—Excellent young Cupressus nevadensis *tree near the end of the fifth growing season on the Alton 8-acre study area. September 1981.*

Figure 37 —Five-year-old Cercocarpus montanus *established from container-grown planting stock on the Alton 8-acre study area. September 1981.*

Figure 38.—Six-year-old Ephedra viridis *established from container-grown planting stock on the Alton 8-acre study area. September 1982.*

Figure 39.—Five-year-old Ribes aureum *established from container-grown planting stock on the Alton 8-acre study area. September 1981.*

Shrub Plantings of 1980

Survival of shrubs and herbaceous species planted in May 1980 was excellent even though no supplemental water was applied. Table 36 shows the mean percent survival and the mean height and diameter of the 27 accessions at the end of the third growing season. Several mountain-mahogany plants were killed by deer browsing, and one rabbitbrush, one globemallow, and three winterfat plants were killed by foraging ants. Much deer use in this area occurs during the growing season. Species favored by deer were cercocarpus, penstemon, cliffrose, skunkbush, desert bitterbrush, Utah sweetvetch, rose, hybrid poplar, Utah serviceberry, velvet ash, chokecherry, and Gambel oak.

Although the accessions of globemallow used appear to be short-lived, a number of young plants were observed near the original plants. At least a dozen species produced seed by the second or third growing seasons (table 36). Most of the plant species tested on this site were growing reasonably well after 3 years. A better assessment of the potential of each species can be made after several more years.

Table 36.—Mean percent survival, mean height, and mean diameter of 29 accessions of plants 3 years after planting, Alton coal field

Species symbol[1]	Mean survival	Mean height	Mean crown diameter
	Percent	*Inches*	
ACLA	100	26*	34
AMUT	90	10	13
ARFI	75	36*	42
CELE[2]	95	14	28
CEBE	70	12	13
CELA	68	10*	16
CEMO	75	8	10
CEPA	90	23*	28
CHNA	95	35*	48
COST	100	14	16
CUNE	90	24	20
ERCO	95	16*	23
FAPA	85	28*	28
FRVE	90	12	13
HEBO	90	12*	18
HIJA	94	16*	15
JUHO	100	7	11
PEVE	100	22*	22
POPZ	90	18	24
PRVI	75	6	5
PUGL	95	13	19
QUGA	85	8	6
RHTR	100	22	26
ROWO (Montana)	95	26	31
ROWO (Alton)	100	18	22
SPCO	55	12*	20
SPPA	45	17*	17
STCO	89	16*	10
YUCCA	100	9	10

[1]See appendix table 69 for plant symbol key.
*These species produced some seed in 1 or more years.

Fourwing Saltbush Ecotypes

First-season survival of 20 ecotypes of fourwing saltbush was 100 percent except for one ecotype that lost two plants as a result of soil erosion. Maximum height among ecotypes ranged from 8 to 22 inches (20 to 56 cm), and maximum crown diameter ranged from 7 to 21 inches (18 to 53 cm).

With the exception of a single plant of the Adrian, Oreg., ecotype, all mortality in the first winter season, 1980 to 1981, occurred among ecotypes from south of 34° N latitude. Among those ecotypes, percentage of mortality was: Guaymas (Mexico), 87 percent; Yuma, 40; Tucson, 27; and Joshua Forest, 27. By spring 1982, all plants of the Yuma and Guaymas ecotypes had died because they lacked winter hardiness.

Table 37 shows mean percent survival, mean height, and mean diameter of each ecotype at the end of the

Table 37.—Mean percent survival, mean height, and mean diameter of 20 ecotypes of *Atriplex canescens* after three growing seasons, Alton coal field

Ecotype source	Mean survival	Mean height	Mean crown diameter
	Percent	*Inches*	
Holbrook, AZ	100	37	50
Tuba City, AZ	93	37	46
Tucson, AZ	47	25	17
Yuma, AZ	0	—	—
Yuma (35 E.), AZ	87	27	20
Joshua, CA	13	18	21
Delta, CO	100	40	47
Guaymas, Mexico	0	—	—
Tularosa, NM	100	37	35
Bernalillo, NM	93	38	56
Adrian, OR	93	26	37
Nyssa, OR	100	32	42
Excel Canyon, UT	100	36	43
Sanpete Co., UT	100	38	50
Huntington, UT	[1]80	23	37
Jericho, UT	100	47	44
Jericho, UT (gigas)	100	49	42
Johnson Canyon, UT	100	39	47
Myton, UT	100	34	42
Douglas, WY	100	17	25

[1]Only mortality was caused by soil erosion.

third growing season. Growth rate was excellent for several of the ecotypes (fig. 40). Considerable difference in morphologic features was apparent, especially in leaf size, leaf shape, and branching habit.

The recent release by the U.S. Department of Agriculture of the certified variety 'Rincon' fourwing saltbush provides an additional ecotype that should be tested on the soils of the Alton coal field. From the standpoint of climatic criteria, it appears well suited to the Alton area.

Figure 40.—Three-year-old Atriplex canescens *on the Utah International bulk sample site, Alton study area. The plant in the left foreground is a female plant of the Bernalillo, New Mexico, ecotype. The plant in the right foreground is a male plant of the same ecotype. September 1982.*

Compatibility of Shrub Species with Grasses

All shrub species interplanted on the perennial grass species test plots on the 3-acre (1.2-ha) area showed excellent survival at the end of the first growing season. However, differences in survival among species were evident by the end of the study (table 38).

Table 38.—Number of surviving plants,[1] mean height, and mean crown diameter of 10 shrub species growing on four soil materials at the Alton 3-acre study site at the end of the first and fifth growing seasons

Species		Sandy loam topsoil			Clay loam subsoil			Carbonaceous shale			Silty clay subsoil			Means		
symbol[2]	Year	No.	Ht.	Dia.	No.	Ht.	Dia.	No.	Ht.	Dia.	No.	Ht.	Dia.	No.	Ht.	Dia.
ATCA	1978	22	7	6	22	18	18	22	16	17	22	6	7	22	12	12
	1982	17	13	9	22	40	44	18	26	20	21	24	23	20	27	25
ATBO	1978	20	5	4	22	8	8	22	11	11	22	5	4	22	7	7
	1982	6	4	4	5	18	17	7	3	4	15	7	8	8	7	8
CELA	1978	22	10	6	20	6	4	22	10	7	22	8	4	22	8	5
	1982	14	15	10	9	7	5	6	3	5	13	12	10	10	11	8
CELE	1978	20	7	3	22	4	2	21	4	2	20	5	2	21	5	2
	1982	15	14	12	20	9	9	*	—	—	19	15	14	18	14	13
CEMO	1978	21	9	2	22	7	3	20	7	3	22	10	3	21	8	3
	1982	9	12	9	17	9	9	17	22	17	21	16	14	16	15	13
EPVI	1978	22	7	4	22	7	4	22	7	3	22	7	4	22	7	4
	1982	9	11	7	20	10	5	10	8	4	21	15	10	15	12	7
KOPR	1978	18	4	4	21	14	19	20	7	10	22	4	5	20	7	10
	1982	12	18	10	20	29	24	7	16	15	18	20	16	14	22	17
KOVI	1978	22	10	7	22	12	12	22	7	7	22	6	5	22	9	8
	1982	19	24	12	19	38	23	15	19	19	22	19	16	19	25	17
PUTR	1978	12	8	4	21	7	7	21	7	4	19	7	4	18	7	5
	1982	12	19	22	21	24	28	17	31	39	17	26	38	17	25	32
RHTR	1978	21	9	3	22	8	3	22	7	3	22	9	3	22	8	3
	1982	18	10	9	19	10	10	22	12	14	20	15	20	20	12	13
Mean	1978	20	8	4	22	9	8	21	9	7	22	7	4	21	8	6
	1982	13	15	11	17	21	19	12	18	18	19	17	17	16	18	16

[1]Twenty-two plants of each species were planted on each soil.
[2]See appendix table 69 for plant symbol key.
*All plants lost as a result of being covered by soil sloughing from terrace "high wall."

Fourwing saltbush, skunkbush, villous prostrate summercypress, and curlleaf cercocarpus exhibited the highest overall survival. Nearly all bitterbrush mortality occurred in the first growing season. Bonneville saltbush and winterfat were the least successful species on the four soil materials, although the former species made fairly good growth on the clay loam subsoil.

Table 39 shows the overall survival, mean height, and mean diameter of all shrubs, in competition with each of the grass species. Shrub survival and growth was poorest on plots of two of the most vigorous of the rhizomatous grasses, intermediate wheatgrass and pubescent wheatgrass. Overall, survival of shrubs was higher in competition with bunchgrasses than with rhizomatous grasses.

Judged on the basis of rate of growth over 5 years, bitterbrush, fourwing saltbush, and the two forms of prostrate summercypress were best able to compete with the established grasses.

Shrubs competed more successfully with grass on the clay loam subsoil than on the sandy loam topsoil. Only one shrub species, winterfat, showed both higher survival and better growth on the sandy loam soil. On plots of carbonaceous shale and silty clay subsoil, where grasses were sparse, overall percent survival was higher on the silty clay. However, there was little difference in shrub growth on the two soil materials. Survival of curlleaf cercocarpus, prostrate summercypress, and winterfat was decreased on carbonaceous shale plots as a result of sloughing of the 8-ft (2.4-m) "high walls" on the uphill side of the two terraces.

Characterization of the Microclimate

The automatic data logging system installed at the 8-acre (3.2-ha) study area in May 1979 functioned almost flawlessly. In February 1982 the soil temperature sensor at the 8-inch (20-cm) depth became defective and was not replaced until June 1982. Appendix tables 61 through 64 show summaries of air and soil temperature data obtained over the 40-month study.

The long-term mean annual temperature given by NOAA for the town of Alton is 45.3° F (7.4° C), as shown in appendix table 65. The mean annual temperature, for the 2 years for which we have complete data at the Alton study area was 48.2° F (9.0° C) in 1980, and 50.7° F (10.4° C) in 1981. The mean annual temperature at Alton for those years was 46.4° F (8.0° C) and 47.8° F (8.8° C) in 1980 and 1981, respectively.

In EMRIA Report No. 4-1975 (USDI 1975), the mean number of frost-free days at the town of Alton is given as 120, with a range of 73 to 151. For the years 1938 through 1981, the mean number of frost-free days was 112, with a range the same as that given above. From 1938 to 1981, the average date of last spring frost was June 5 (median = June 4), and the average date of first autumn frost was September 25 (with same median). During the years in which data were obtained at the 8-acre study area, the frost-free period ranged from 141 days in 1980 and 1982, to 156 days in 1979 (appendix table 66). The frost-free period at a height of 12 inches (30 cm) above ground ranged from 96 days in 1982 to 118 days in 1979, and was quite similar to the frost-free

Table 39.—Overall survival, mean height, and mean crown diameter of all shrubs, in competition with 11 different species of grass, after 5 years, Alton coal field.

Competing grass species[1]	All shrubs combined		
	Survival	Mean height	Mean diameter
	Percent	*Inches*	
AGCR	74	17	15
AGEL	68	15	13
AGIN	70	22	21
AGIN[2]	58	14	12
AGRI	75	18	17
AGSM	76	17	16
AGCR(r) or AGSP x AGRE[2]	59	20	19
AGTR[2]	60	14	12
BRIN	69	18	16
ELCI	78	18	18
ELJU	76	18	17

[1]See appendix table 69 for plant symbol key.
[2]The AGSP x AGRE hybrid and the rhizomatous form of AGCR were each planted on half of a single plot on each soil.

period reported for Alton in each year. As mentioned in the description of the Emery microclimate, the "growing season" for most native or introduced plant species is usually of greater length than the frost-free period.

Appendix table 67 shows calculations of the number of growing degree days at the Alton study area from 1979 through 1982. The growing degree days were calculated in the same manner as shown in appendix table 48 for the Emery study area.

The long-term mean precipitation received each month and the annual mean for the town of Alton is shown in appendix table 65. Appendix table 68 shows the precipitation received during each month from October 1976 through September 1982 at the town of Alton, and for each month from May 1979 through September 1982 at the Alton study area.

As previously mentioned, the growing season of 1977 was not a good one in which to establish a stand of vegetation by direct seeding. Had it not been for a "wet" May and greater than average rainfall in July, all study areas seeded in autumn 1976 might have remained nearly bare. Since 1953, the months of October through April (the period of soil moisture accumulation) at Alton have typically received approximately 63 percent of the total precipitation for the water year, October 1 to September 30. However, from 1977 to 1978, 1978 to 1979, and 1979 to 1980, considerably above average precipitation was received in the October to April period (table 40). On the other hand, in 3 of the 6 years of our study, less than average amounts of rainfall occurred during the growing season. The 1979 and 1980 water years were unusually wet, with 22.32 and 23.93 inches (567 and 608 mm) of precipitation, respectively.

From 1953 through 1981, there were only five unusually wet years (more than 40 percent greater than average) and two unusually dry years.

Appendix table 66 shows some additional data obtained on microclimatic factors at the Alton 8-acre study area.

Table 40.—Precipitation received (inches) at the town of Alton, Utah, according to periods of the "water year," 1977 through 1982

October 1 to April 30		May 1 to September 30		Total
1976–77	2.20	1977	7.72	9.92
1977–78	13.79	1978	3.02	16.81
1978–79	19.30	1979	3.02	22.32
1979–80	15.25	1980	8.68	23.93
1980–81	6.02	1981	5.69	11.71
1981–82	10.85	1982	7.28	18.13
Long term:	10.36	Long term:	6.02	16.38

CONCLUSIONS AND RECOMMENDATIONS

Based on data obtained and observations made over a 6-year study on the Alton coal field, we reached the following conclusions and recommendations:

1. The incorporation of a grass hay soil amendment into the top 8 inches (20 cm) of restored topsoil (2.5 tons per acre or 5.6 per ha) should increase the initial establishment of grass, legume, and shrub seedlings on severely disturbed sites. However, a hay soil amendment is not recommended when topsoil of satisfactory quality is present, because our studies indicate that within a few years stand density becomes quite similar on amended and nonamended areas. The addition of an organic soil amendment can increase grass establishment and increase production if subsoil material has to be used on the surface of a reclaimed area.

2. Adequate vegetative stand density can be established to protect the soil from erosion on slopes of 15 percent or less by gouging the soil surface followed by broadcast seeding.

3. "Nomad" alfalfa will probably exhibit a gradual decrease in plant numbers following initial establishment in a mixed grass-alfalfa seeding, but should remain a significant contributor to the total herbage yield for at least 6 years.

4. Fourwing saltbush, bitterbrush, and cliffrose are capable of persisting in competition with grasses and legumes on reclaimed sites, although the latter two species cannot be expected to contribute significant amounts of forage until the fifth or sixth year.

5. Winterfat and green ephedra are unsuited for inclusion in seed mixtures used for revegetation in the Alton coal field area because they are poor competitors with perennial grass and legume mixtures.

6. Yield of grasses should be significantly higher on reclaimed areas where topsoil is returned to the area than where local subsoil material is revegetated.

7. "Introduced" species of grass can be expected to outyield "native" species for the first 3 or 4 years following seeding. However, by the fifth or sixth year, well-adapted native species should equal most introduced species in herbage yield.

8. Based on our studies, perennial grass species that appear well adapted to the climate and soils of the Alton coal field are basin wildrye, 'Alkar' tall wheatgrass, 'Whitmar' beardless bluebunch wheatgrass, intermediate wheatgrass, smooth bromegrass, 'Luna' pubescent wheatgrass, 'Fairway' crested wheatgrass, and 'Nordan' crested wheatgrass. The above species are listed in approximate order of highest herbage yield after 6 years. Other species that appear adapted, but are lower yielding species during the first 6 years, are Russian wildrye, 'Rosana' western wheatgrass, and 'Sodar' streambank wheatgrass.

9. Sandy loam topsoil, of the fine-loamy Typic Argiustolls subgroup described as 4008 on page 16 of EMRIA Report No. 4-1975 (USDI 1975), is perhaps the best soil material for use on the surface of reclaimed areas on the Alton coal field. However, loam topsoil that occurs chiefly in alluvial deposits, and some clay loam subsoil, similar to that used on our 3-acre (1.2-ha) study area, should sustain excellent stands of herbaceous vegetation. Carbonaceous shale overlain by 10 to 12 inches (25 to 30 cm) of either sandy loam topsoil or loam topsoil, should produce better stands of vegetation than carbonaceous shale alone. The addition of inorganic fertilizer is recommended as a soil amendment if carbonaceous shale is used as a surface material.

10. Neither soil salinity nor soil sodicity should be a significant barrier to plant growth on areas where at least 10 inches of topsoil are placed over carbonaceous shale overburden.

11. Excellent results in establishing desirable shrubs, trees, and even forbs, can be obtained on the Alton coal field by using container-grown nursery stock. Planting should be done before May 15. The provision of 1 or 2 qt (1 or 2 liters) of water to each plant at the time of planting is recommended.

12. On the basis of our 6-year study, the following species of forbs and woody plants are recommended for use on reclaimed areas of the Alton coal field:

Primary species:

Wood's rose	Green ephedra
Antelope bitterbrush	Squawapple
Cliffrose	Golden currant
Fourwing saltbush	Corymbed eriogonum
Skunkbush sumac	Utah sweetvetch
Black sagebrush	Common globemallow
Mountain big sagebrush	Beautiful penstemon
Rubber rabbitbrush	Palmer penstemon
Curlleaf cercocarpus	Western yarrow
Alderleaf cercocarpus	

Secondary species:

Siberian peashrub	Apacheplume
Russian-olive	Prostrate summercypress
Tatarian honeysuckle	Plumed whitesage
Sand sagebrush	

13. Fourwing saltbush ecotypes from southern Arizona and southern California have little chance to survive on the Alton coal field because they lack winter hardiness. Continued evaluations of ecotypes of this valuable forage species should be made on the Alton coal field.

14. Shrub survival and growth are better when shrubs are established in stands of perennial bunchgrass than when forced to compete with vigorous rhizomatous species. On areas where good shrub establishment is considered an important objective, consideration should be given to excluding rhizomatous grasses from the seed mixture.

15. Plants with aerial parts growing within 12 inches (30 cm) or so of the soil surface are exposed to a greater number of late spring and early autumn frosts than would be indicated by temperature data recorded at 54 inches (137 cm) above the surface. At the Alton 8-acre study site, frost-free periods from 1979 to 1982 ranged from 28 to 45 days shorter at 12 inches above ground than at 54 inches above ground.

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APPENDIX

Tables 41-69

Figures 41-62

Table 41.—Species of shrubs planted at seven sites within the Emery study area in 1978 and 1979

Scientific name	Source	Sites planted[1]
Artemisia nova	Kane Co., UT	1,2,3,4
Atriplex aptera	Yellowstone Co., MT	1,2,3,4,5
Atriplex bonnevillensis	Millard Co., UT	1,2,3,4,5
Atriplex canescens	Different sources[2]	1,2,3,4,5,6,7
A. canescens x *A. cuneata*	Wayne Co., UT	1,2,3,4,5
A. canescens x *A. idahoensis*[3]	Owyhee Co., ID	2,4,5,6
A. canescens x *A. obovata*	Sandoval Co., NM	6,7
A. canescens x *A. tridentata*	Tooele Co., UT	2,3,4,5,6,7
A. canescens x *A. confertifolia* x *A. canescens*	Churchill Co., NV	6,7
A. corrugata x *A. cuneata*	San Juan Co., NM	6,7
Atriplex falcata	Nevada	6,7
Atriplex gardneri[4]	Tooele Co., UT	1,2,3,4,5
Atriplex idahoensis[3]	Owyhee Co., ID	1,3,5
Atriplex lahontanensis[3]	Lander Co., NV	6,7
Atriplex navajoensis	Coconino Co., AZ	1,2,3,4
Atriplex obovata	San Juan Co., UT	1,2,3,4,5
Atriplex robusta[3]	Tooele Co., UT	1,2,3,4,5,6
Atriplex tooelensis[3]	Tooele Co., UT	1,2,3,4
Atriplex tridentata	Uintah Co., UT	1,2,3,4,5
A. tridentata x *A. bonnevillensis*	Juab Co., UT	6,7
Camphorosma monspeliaca	U.S.S.R.	1,2,3,4,5
Ceratoides lanata	Uintah and Kane Co., UT	1,2,3,4,5
Ceratoides papposa	U.S.S.R.	2,4,5
Ephedra nevadensis	Millard Co., UT	1,2,3,4
Eriogonum corymbosum	Emery Co., UT	1,2,4
Grayia spinosa	Uintah Co., UT and Kern Co., CA	1,2,3,4
Kochia prostrata	U.S.S.R.	1,2,3,4,5
Kochia prostrata villosissima	U.S.S.R.	1,2,3,4,5

[1]Sites: 1 = Persayo soil, 2 = Penoyer soil, 3 = Castle Valley soil, 4 = shaley subsoil, 5 = Bluegate shale, 6 = Persayo soil *Atriplex* plots, 7 = Castle Valley soil *Atriplex* plots.
[2]ATCA sources: sites 1 – 5 = Kane Co., Utah; sites 6 and 7 = Yuma Co., Ariz., and Juab Co., Utah.
[3]Undescribed taxa, provided by Dr. Howard Stutz.
[4]Subsequently identified as *Atriplex tridentata*.

Table 42.—Mean air and soil temperatures (°C) for each month, May 16, 1979, through December 1982, Emery 6-acre study area

Date		Air at 54"	Soil temperature: Persayo series −2"	Persayo series −8"	Shaley subsoil −2"	Shaley subsoil −8"
1979	May (16-31)	16.4	17.2	16.2	18.1	16.8
	June	19.8	20.8	19.3	21.5	19.8
	July	24.1	25.4	23.6	25.3	23.4
	August	21.0	22.2	21.8	22.7	22.0
	September	19.7	19.5	19.5	20.6	20.2
	October	11.7	12.0	13.5	13.4	14.8
	November	−.8	−.3	2.3	1.0	4.2
	December	−2.6	−4.5	−2.7	−3.0	−.5
1980	January	−2.2	−1.5	−.6	−1.3	.1
	February	.7	−.7	−.1	−.6	.3
	March	1.2	2.7	2.9	2.4	3.0
	April	7.9	7.8	7.4	9.0	8.2
	May	10.8	12.2	11.9	12.3	12.0
	June	20.5	19.7	18.3	20.5	18.9
	July	24.0	24.2	22.8	24.7	23.1
	August	21.4	22.7	22.2	23.0	22.4
	September	16.5	16.4	16.8	16.7	17.2
	October	9.5	8.6	9.9	9.4	11.2
	November	3.4	1.9	3.1	2.5	4.3
	December	2.0	−1.4	−.4	−.7	.9
	Annual mean	9.6	9.4	9.6	9.8	10.1
1981	January	1.0	−1.2	−.4	−.5	.9
	February	1.0	−.3	.1	.5	1.3
	March	2.8	3.4	3.5	3.2	3.8
	April	10.8	10.5	9.8	11.2	10.2
	May	12.1	14.5	13.8	14.5	13.9
	June	21.0	22.3	20.6	21.7	19.8
	July	23.3	24.4	23.2	24.1	22.8
	August	21.6	22.4	21.9	22.4	21.9
	September	17.7	17.5	17.8	17.9	18.3
	October	7.9	8.0	9.3	8.4	10.5
	November	3.6	—	2.6	2.8	4.9
	December	−1.3	—	−1.2	−2.0	0
	Annual mean	10.3		10.2	10.4	10.7
1982	January	−4.6	—	−2.0	−4.3	−2.5
	February	−2.8	—	−2.2	−2.8	−2.1
	March	2.9	—	3.3	3.2	3.4
	April	6.6	—	7.2	8.3	7.7
	May	12.5	—	13.2	14.8	13.5
	June	17.9	—	18.3	20.3	18.2
	July	22.2	—	22.6	24.3	22.2
	August	20.8	—	21.3	22.0	21.5
	September	15.1	—	16.7	16.6	17.5
	October	6.6	—	7.7	7.5	9.0
	November	−.1	—	1.0	.5	2.6
	December	−3.8	—	−2.2	−3.7	−1.5
	Annual mean	7.8	—	8.7	8.9	9.1

Table 43.—Mean maximum air and soil temperatures (°C) for each month, May 16, 1979, through December 1982, Emery 6-acre study area

			Soil temperature			
			Persayo series		Shaley subsoil	
Date		Air at 54″	− 2″	− 8″	− 2″	− 8″
1979	May (16-31)	24.6	23.8	18.1	23.8	18.3
	June	28.8	28.5	21.4	28.0	21.3
	July	33.3	33.6	25.3	32.0	24.6
	August	29.8	29.9	23.5	29.3	23.1
	September	29.3	27.3	21.0	27.6	21.3
	October	20.5	18.5	14.7	19.0	15.7
	November	5.9	3.3	3.1	4.5	5.0
	December	4.1	-2.0	-2.0	.1	0
1980	January	4.2	-.6	-.3	.1	.4
	February	8.6	.9	.4	1.1	.8
	March	7.8	5.0	3.7	5.5	3.9
	April	16.3	11.3	8.6	13.8	9.4
	May	18.3	16.3	13.3	17.5	13.4
	June	29.3	24.7	19.7	26.0	20.1
	July	32.9	29.9	24.3	31.3	24.3
	August	30.0	28.5	23.5	29.7	23.4
	September	24.9	21.3	17.4	21.2	18.4
	October	17.5	13.5	11.0	14.6	12.2
	November	11.4	4.4	2.8	5.9	5.1
	December	11.0	.2	.1	2.7	1.5
	Annual mean	17.6	13.0	10.5	14.1	11.1
1981	January	9.4	1.0	.2	3.1	1.6
	February	9.2	3.2	.9	5.1	2.0
	March	10.2	6.3	4.5	7.4	4.7
	April	19.0	14.8	11.2	16.8	11.6
	May	19.4	19.1	15.2	19.7	15.0
	June	29.9	28.5	22.2	28.7	21.1
	July	32.2	30.7	24.9	31.2	24.1
	August	31.7	29.2	23.5	30.0	23.2
	September	26.9	23.4	19.5	24.6	19.6
	October	15.4	12.7	10.5	13.7	11.5
	November	11.7	—	4.6	7.2	5.7
	December	6.6	—	-.6	.6	.5
	Annual mean	18.5	—	11.4	15.7	11.7
1982	January	4.1	—	-1.8	-2.4	-2.2
	February	6.4	—	-1.7	1.5	-1.5
	March	9.1	—	4.3	8.4	4.4
	April	14.4	—	8.6	15.0	9.1
	May	20.4	—	14.4	22.1	17.9
	June	26.8	—	19.8	29.0	19.5
	July	31.3	—	24.1	33.2	23.4
	August	30.5	—	22.9	30.1	22.7
	September	23.2	—	18.1	23.2	18.6
	October	15.0	—	9.0	13.1	10.1
	November	7.7	—	1.7	5.1	3.3
	December	4.2	—	-1.7	-2.9	-1.2
	Annual mean	16.1	—	9.8	14.6	10.3

Table 44.—Mean minimum air and soil temperatures (°C) for each month, May 16, 1979, through December 1982, Emery 6–acre study area

Date		Air at 54"	Soil temperature			
			Persayo series		Shaley subsoil	
			– 2"	– 8"	– 2"	– 8"
1979	May (16–31)	8.9	11.6	14.4	13.1	15.6
	June	10.9	14.0	17.4	15.6	18.6
	July	15.5	18.3	21.9	19.4	21.7
	August	13.5	16.0	20.2	17.1	21.0
	September	11.9	13.5	18.0	14.9	19.2
	October	5.5	7.3	12.3	8.9	14.1
	November	–5.9	–3.2	1.6	–1.8	3.5
	December	–7.5	–7.0	–3.3	–5.4	–1.0
1980	January	–6.7	–2.3	–.9	–2.5	–.2
	February	–4.4	–1.7	–.7	–1.8	0
	March	–4.0	1.1	2.3	.5	2.4
	April	.3	4.8	6.4	4.9	7.2
	May	4.6	8.4	10.7	8.1	10.9
	June	11.5	15.0	16.9	15.2	17.7
	July	15.4	19.0	21.5	19.0	21.3
	August	13.3	17.6	20.9	16.8	21.4
	September	9.2	12.4	14.9	11.9	16.2
	October	3.4	5.5	8.7	5.6	10.3
	November	–2.2	–.2	2.5	–.1	3.8
	December	–3.4	–3.0	–.2	–2.9	.5
	Annual mean	3.1	6.4	8.6	6.2	9.3
1981	January	–4.4	–2.9	–.8	–3.0	.4
	February	–5.2	–3.1	–.7	–3.0	.7
	March	–2.2	1.4	2.7	.5	3.0
	April	3.7	6.7	8.6	6.4	9.1
	May	5.2	10.5	12.7	10.1	13.0
	June	12.5	16.8	19.1	15.8	18.7
	July	15.4	18.8	21.7	18.2	21.7
	August	13.7	16.8	20.4	16.4	20.8
	September	10.8	12.9	16.2	12.6	17.1
	October	2.4	4.5	8.1	4.4	9.5
	November	–2.0	—	2.7	–.4	4.2
	December	–6.4	—	–1.6	–3.8	–.3
	Annual mean	3.6	—	9.1	6.2	9.8
1982	January	–10.0	—	–2.2	–6.1	–2.8
	February	–8.4	—	–2.6	–6.0	–2.6
	March	–2.0	—	2.4	–.7	2.6
	April	–.8	—	6.0	2.9	6.5
	May	5.3	—	11.9	8.9	12.4
	June	9.5	—	16.9	13.2	17.1
	July	14.0	—	21.2	17.1	21.1
	August	13.6	—	19.8	15.8	20.5
	September	8.9	—	15.6	11.7	16.6
	October	.4	—	6.4	3.2	8.0
	November	–5.4	—	.2	–2.9	1.9
	December	–8.1	—	–2.5	–4.4	–1.7
	Annual mean	1.4	—	7.6	4.4	8.3

Table 45.—Extreme maximum and minimum temperatures (°C) recorded at the Persayo-soil study site for each month, from May 1979 through Dercember 1982, Emery coal field

Month		1979			1980			1981			1982		
		Air	Soil		Air	Soil		Air	Soil		Air	Soil	
		at 54″	2″	8″	at 54″	2″	8″	at 54″	2″	8″	at 54″	2″	8″
Jan.—	Max.	—	—	—	11.9	4.8	2.0	16.1	4.2	1.5	13.5	—	−0.9
	Min.	—	—	—	−12.6	−8.1	−3.0	−9.4	−5.0	−2.0	−22.1	—	−2.8
Feb.—	Max.	—	—	—	15.4	6.0	3.5	15.1	7.0	3.7	20.1	—	4.0
	Min.	—	—	—	−12.4	−6.5	−3.6	−14.3	−6.6	−3.0	−21.2	—	−7.7
Mar.—	Max	—	—	—	13.1	7.8	4.8	17.4	10.1	6.9	17.1	—	6.5
	Min.	—	—	—	−11.7	.2	1.5	−6.6	−.8	1.2	−6.4	—	.9
Apr.—	Max.	—	—	—	26.1	17.4	13.3	28.3	21.5	16.7	24.9	—	12.9
	Min.	—	—	—	−10.7	0	1.2	−6.5	1.1	3.7	−7.6	—	3.2
May.—	Max.	29.3	28.1	19.9	29.6	21.1	16.6	28.8	24.4	18.5	28.9	—	17.7
	Min.	2.6	7.7	12.7	−1.4	5.4	8.3	−1.5	6.3	9.8	−.9	—	9.2
June—	Max.	37.1	34.1	24.4	34.5	29.2	23.0	38.8	34.5	25.7	34.1	—	23.8
	Min.	3.8	9.2	13.4	5.0	9.5	11.7	3.2	11.5	14.6	.8	—	13.1
July—	Max.	37.2	37.0	27.0	38.2	33.9	26.5	38.3	34.2	26.8	38.3	—	26.2
	Min.	9.3	14.7	19.4	10.6	14.3	18.3	12.4	16.3	19.5	4.5	—	17.6
Aug.—	Max.	38.1	36.2	27.3	36.7	34.2	26.7	38.7	34.8	26.7	36.7	—	25.5
	Min.	7.6	10.7	16.0	6.6	13.2	17.6	9.3	12.6	17.4	9.8	—	17.4
Sept.—	Max.	33.8	31.0	22.9	33.6	27.8	21.7	33.3	28.3	22.2	33.5	—	22.4
	Min.	6.4	9.6	15.7	2.6	8.7	12.7	6.1	9.3	13.6	1.7	—	9.3
Oct.—	Max.	29.4	23.8	19.1	30.4	20.2	16.6	26.7	21.6	17.4	21.1	—	11.6
	Min.	−7.3	−2.0	5.0	−5.1	−.4	2.8	−5.0	−.7	3.4	−5.2	—	3.3
Nov.—	Max.	12.1	9.0	6.8	21.1	10.2	7.9	20.6	[1]	7.1	17.0	—	6.2
	Min.	−13.9	−12.5	−5.7	−10.5	−5.1	−.9	−10.2	—	−.7	−10.8	—	−3.2
Dec.—	Max.	9.1	.8	.7	17.4	3.4	1.5	15.7	—	.8	9.5	—	.3
	Min.	−15.5	−13.9	−6.2	−8.7	−6.7	−2.7	−13.7	—	−4.1	−16.7	—	−6.7

[1]Temperature sensor ceased functioning in November 1981.

Table 46.—Mean temperature (°C) for each month, for the period 1955 to 1982 at Ferron, Utah

Month	Mean	Range	Month	Mean	Range
Jan.	−5.1	−9.6— 1.2	Jul.	22.4	21.3—24.2
Feb.	−1.8	−8.7— 2.8	Aug.	21.0	17.6—22.8
Mar.	2.6	−.1— 6.6	Sept.	16.3	13.0—19.1
Apr.	7.7	4.1—10.6	Oct.	10.1	5.9—12.6
May	13.2	9.8—16.2	Nov.	3.0	−.3— 5.3
June	18.8	15.3—23.6	Dec.	−3.1	−7.4— 1.6

Annual mean = 8.7, Range = 7.5—10.1

Table 47.—Miscellaneous microclimatic data from the Emery study area

Item	1978[1]	1979	1980	1981	1982
Length of frost-free period (days)	134	168	142	158	147
No. days 0 °C or lower (5/1 – 10/15)	7	0	13	4	8
Extreme min. temp. (5/1 – 10/15)	−4.0	2.6	−5.1	−2.7	−3.4
No. days 32.2 °C, or higher	[2]38	43	45	42	28
No. days 32.2 °C or higher at Ferron	19	28	21	28	8
Dates between which the mean daily soil temp. of Persayo soil at 8 inches was 10 °C or higher	?	? 10/23	4/20 – 10/15	4/14 – 10/11	4/27 – 10/1
Max. rainfall in 1 hour (inches)	?	0.12	0.29	0.73	0.23
Max. rainfall in 24 hours (inches)	0.26	0.12	1.20	1.23	0.46
Max. rainfall in 7 days (inches)	0.57	0.13	2.19	2.64	1.00
No. consecutive days with no recorded rainfall ⩾ 0.25 inches (5/1 – 10/15)	87	184	60	58	103

[1]1978 data from Ferron, Utah.
[2]Predicted from correlation between Ferron and Emery study area.

Table 48.—Cumulative growing degree days (°C) at the Emery study area for the years 1979 through 1982

Week beginning	1979	1980	1981	1982
Jan. 3	0	4	20	6
17	0	22	71	19
31	0	60	90	28
Feb. 14	6	88	133	60
Mar. 1	14	130	186	112
15	48	167	220	158
29	83	191	285	208
Apr. 12	172	270	415	277
26	279	386	562	375
May 10	373	484	658	477
24	550	610	796	629
June 7	730	794	1,002	787
21	933	1,006	1,197	984
July 5	1,162	1,230	1,410	1,185
19	1,396	1,469	1,645	1,428
Aug. 2	1,641	1,713	1,879	1,656
16	1,838	1,925	2,085	1,878
30	2,057	2,126	2,302	2,091
Sept. 13	2,264	2,299	2,490	2,243
27	2,469	2,470	2,676	2,374
Oct. 11	2,647	2,606	2,758	2,462
25	2,724	2,666	2,841	2,534
Nov. 8	2,759	2,752	2,923	2,576
22	2,774	2,786	2,966	2,598
Dec. 6	2,790	2,815	3,009	2,614
20	2,802	2,882	3,023	2,627
27	2,804	2,920	3,030	2,627

Table 49.—Long-term mean precipitation (inches) received at Emery, Utah, and precipitation received at the Emery study area during the period of study

Month	Long-term means for Emery, Utah	Precipitation during the study period					
		1977	1978	1979	1980	1981	1982
Jan.	0.47	[1]0.32	1.48	3.14	2.44	0.04	1.63
Feb.	.41	.20	1.67	.87	1.80	.04	.12
Mar.	.45	0	1.08	3.03	1.20	1.11	.49
Apr.	.42	.16	.33	.28	.50	.36	.03
May	.62	1.21	[2].57	[4].47	1.55	.33	.13
June	.69	.73	[3].06	.02	.10	1.13	.14
July	.71	1.17	.49	.01	.48	.33	.25
Aug.	1.17	1.13	.23	.07	.35	1.21	1.06
Sept.	.79	.45	.18	.13	2.23	2.82	1.32
Oct.	.85	.49	.30	.09	.62	1.27	0
Nov.	.40	.02	2.58	.27	.30	.26	.57
Dec.	.57	.40	.64	.19	.02	.18	.46
Annual mean	7.55	6.28	9.61	8.57	11.59	9.08	6.20

[1]Data from Emery, Utah, January 1977 through April 1978.
[2]Data from Ferron, Utah, May and December 1978, February 1979, December 1979 through March 1980, November and December 1980, and January 1982.
[3]Data from USGS gage in June through November 1978, and January and March 1979.
[4]Data from Emery study area, beginning May 1979, except as otherwise noted.

Table 50.—Precipitation received (inches) at the Emery study area, according to periods of the "water year," 1978 to 1982

October 1 to April 30		May 1 to September 30		Total
1977–78	5.47	1978	1.53	7.00
1978–79	7.81	1979	.70	8.51
1979–80	6.49	1980	4.71	11.20
1980–81	2.49	1981	5.82	8.31
1981–82	3.98	1982	2.90	6.88
Mean at Emery	3.57		3.98	7.55

Table 51.—Mean soil water potential as measured by thermocouple psychrometers at Emery study sites in 1980

Soil location	Soil depth	April 22	May 23	June 27	August 15	October 6
	Inches	*Bars*				
Persayo series	8	−7	−5	−9	−30	−2
Cultipacked	20	−6	−6	−9	−51	−8
Gouged	8	−8	−7	−6	−22	−7
	20	−8	−7	−2	−37	−12
Penoyer series	8	−10	−4	−36	−15	−5
Cultipacked	20	−8	−3	−23	−70	−7
Gouged	8	−7	−5	−10	−40	−5
	20	−6	−5	−2	−44	−5
Castle Valley	8	−9	−3	−18	−13	−10
series	20	−4	−5	−17	−70	−74
Bluegate shale	8	−10	−6	−9	−70	−6
Ripped	20	−13	−13	−12	−72	−35
Nonripped	8	−3	−2	−14	−48	−3
	20	−6	−6	−5	−9	−7
Shaley subsoil	8	−7	−6	−7	−16	−27
	20	−10	−12	−10	−12	−11

Table 52.—Mean soil water potential as measured by thermocouple psychrometers at Emery study sites in 1981

Soil location	Soil depth	Apr. 16	May 19	June 18	July 29	Aug. 19	Sept. 14	Oct. 20
	Inches	*Bars*						
Persayo series	8	−1	−6	−44	−70	*	−55	−28
Cultipacked	20	−7	−9	−37	−46	−61	−63	−50
Gouged	8	−1	−1	−28	−55	−52	−1	−1
	20	−4	−3	−20	−55	−66	−27	−1
Penoyer series	8	−1	−20	−76	−54	−79	−26	−7
Cultipacked	20	−1	−20	−60	−69	−75	−76	−48
Gouged	8	−1	−3	−32	−25	−45	−1	−2
	20	−2	−1	−24	−30	−43	−47	−20
Castle Valley	8	−4	−11	−76	−59	*	−11	−9
series	20	−34	−28	−69	−72	−79	−78	−70
Bluegate shale	8	−2	−9	−56	−65	*	−78	−18
Ripped	20	−29	−28	−54	−79	*	−52	−5
Nonripped	8	−1	−19	−45	−20	*	−3	−5
	20	−6	−4	−8	−15	−18	−20	−11
Shaley subsoil	8	−13	−12	−17	−11	−14	−9	−5
	20	−10	−11	−12	−10	−11	−9	−8

* = Soil too dry to obtain readings.

Table 53.—Species of container-grown shrubs planted on grass species plots on the 3-acre study site, Alton coal field

Common name	Scientific name	Source
Bonneville saltbush	*Atriplex bonnevillensis*	Millard Co., UT
Fourwing saltbush	*Atriplex canescens*	Sanpete Co., UT
Winterfat	*Ceratoides lanata*	Sanpete Co., UT
Curlleaf cercocarpus	*Cercocarpus ledifolius*	Utah Co., UT
Alderleaf cercocarpus	*Cercocarpus montanus*	El Paso Co., CO
Green ephedra	*Ephedra viridis*	Sanpete Co., UT
Prostrate summercypress	*Kochia prostrata*	U.S.S.R.
Villous prostrate summercypress	*Kochia prostrata villosissima*	U.S.S.R.
Antelope bitterbrush	*Purshia tridentata*	Nevada
Skunkbush sumac	*Rhus trilobata*	Judith Basin Co., MT

Table 54.—Plant species included in seed mixture sown in November 1976 on the Utah International cooperative study plots, Alton coal field

Common name	Scientific name	Source
'Fairway' crested wheatgrass	*Agropyron cristatum*	Wyoming
'Jose' tall wheatgrass	*Agropyron elongatum*	Colorado
'Rosana' western wheatgrass	*Agropyron smithii*	Montana
Russian wildrye	*Elymus junceus*	Colorado
Indian ricegrass	*Oryzopsis hymenoides*	Kansas
Alkali sacaton	*Sporobolus airoides*	Kansas
'Lutana' cicer milkvetch	*Astragalus cicer*	Wyoming
Arrowleaf balsamroot	*Balsamorhiza sagittata*	Sanpete Co., UT
Utah sweetvetch	*Hedysarum boreale*	Utah Co., UT
'Drylander' alfalfa	*Medicago media*	Saskatchewan
Small burnet	*Sanguisorba minor*	Oregon
Gooseberryleaf globemallow	*Sphaeralcea grossulariaefolia*	Millard Co., UT
Utah serviceberry	*Amelanchier oreophila*	Cassia Co., ID
Fourwing saltbush	*Atriplex canescens*	Kane Co., UT
Winterfat	*Ceratoides lanata*	Garfield Co., UT
Alderleaf cercocarpus	*Cercocarpus montanus*	El Paso Co., CO
Green ephedra	*Ephedra viridis*	Sanpete Co., UT
Antelope bitterbrush	*Purshia tridentata*	Sanpete Co., UT

Table 55.—Species of shrubs and forbs planted at the Alton 8-acre study site in 1977

Common name	Scientific name	Source
Utah serviceberry	*Amelanchier utahensis*	Cassia Co., ID
Indigobush	*Amorpha fruticosa*	Boise Co., ID
Black sagebrush	*Artemisia nova*	Alton, Kane Co., UT
Mountain big sagebrush	*Artemisia vaseyana*	Sanpete Co., UT
Fourwing saltbush	*Atriplex canescens*	Los Lunas, NM
Fremont barberry	*Berberis fremontii*	Garfield Co., UT
Siberian peashrub	*Caragana arborescens*	?
Wedgeleaf ceanothus	*Ceanothus cuneatus*	Jackson Co., OR
Winterfat	*Ceratoides lanata*	Kane Co., UT
Curlleaf cercocarpus	*Cercocarpus ledifolius*	Utah Co., UT
Alderleaf cercocarpus	*Cercocarpus montanus*	El Paso Co., CO
Rubber rabbitbrush	*Chrysothamnus nauseosus*	Sanpete Co., UT
Cliffrose	*Cowania stansburiana*	Salt Lake Co., UT
Piute cypress	*Cupressus nevadensis*	Kern Co., CA
Russian-olive	*Elaeagnus angustifolia*	Emery Co., UT
Green ephedra	*Ephedra viridis*	Sanpete Co., UT
Utah sweetvetch	*Hedysarum boreale*	Utah Co., UT
Prostrate summercypress	*Kochia prostrata*	U.S.S.R. (P.I. 330675)
Tatarian honeysuckle	*Lonicera tatarica*	?
Squawapple	*Peraphyllum ramossisimum*	Lincoln Co., NV
Shrubby cinquefoil	*Potentilla fruticosa*	Garfield Co., UT
Black chokecherry	*Prunus virginiana melanocarpa*	Utah Co., UT
Antelope bitterbrush	*Purshia tridentata*	?
Skunkbush sumac	*Rhus trilobata*	?
Golden currant	*Ribes aureum*	?
Wood's rose	*Rosa woodsii*	?
Blueberry elder	*Sambucus cerulea*	Sanpete Co., UT
Roundleaf buffaloberry	*Shepherdia rotundifolia*	Garfield Co., UT
Gooseberryleaf globemallow	*Sphaeralcea grossulariaefolia*	Sanpete Co., UT

Table 56.—Species of shrubs, forbs, and trees planted on the Alton "bulk sample" site, May 1980

Common name	Scientific name	Source
In randomized blocks:		
Western yarrow	*Achillea lanulosa*	Southern Idaho
Sand sagebrush	*Artemisia filifolia*	Garfield Co., UT
Lemmon's ceanothus	*Ceanothus lemmoni*	Shasta Co., CA
Birchleaf cercocarpus	*Cercocarpus betuloides*	Tehama Co., CA
Winterfat	*Ceratoides lanata*	Kane Co., UT
Plumed sage	*Ceratoides papposa*	U.S.S.R. (P.I. 371860)
Rubber rabbitbrush	*Chrysothamnus nauseosus*	Rio Blanco Co., CO
Cliffrose	*Cowania stansburiana*	Utah
Corymbed eriogonum	*Eriogonum corymbosum*	Kane Co., UT
Apache-plume	*Fallugia paradoxa*	?
Galleta	*Hilaria jamesii*	SCS, Los Lunas, NM
Utah sweetvetch	*Hedysarum boreale*	Salt Lake Co., UT
Creeping juniper	*Juniperus horizontalis*	Rosebud Co., MT
Beautiful penstemon	*Penstemon venustus*	Idaho
Desert bitterbrush	*Purshia glandulosa*	Nye Co., NV
Yucca	*Yucca* spp.	Washington Co., UT
Skunkbush sumac	*Rhus trilobata*	Washington Co., UT
Wood's rose	*Rosa woodsii*	Rosebud Co., MT
Wood's rose	*Rosa woodsii*	Kane Co., UT
Common globemallow	*Sphaeralcea coccinea*	Kane Co., UT
Nelson globemallow	*Sphaeralcea parvifolia*	Kane Co., UT
Needle-and-thread	*Stipa comata*	Salt Lake Co., UT
In windbreak plot:		
Utah serviceberry	*Amelanchier utahensis*	Washington Co., UT
Alderleaf cercocarpus	*Cercocarpus montanus*	El Paso Co., CO
Piute cypress	*Cupressus nevadensis*	Kern Co., CA
Velvet ash	*Fraxinus velutina*	Washington Co., UT
Hybrid poplar	*Populus* spp.[1]	Europe
Western black chokecherry	*Prunus virginiana*	Utah Co., UT
Gambel oak	*Quercus gambelii*	Garfield Co., UT

[1]Five of each of the following were planted: No. 302 (*P.* cv. 'Betufolia' x *P. trichocarpa*), No. NE-4 (*P. nigra* x *P. laurifolia*), No. 253 (*P.* cv. 'Angulata' x *P. trichocarpa*), and No. 353 (*P. deltoides* x *P.* cv. 'Caudina').

Table 57.—Seed source of 20 accessions of fourwing saltbush planted in May 1980 on the Alton bulk sample site

Holbrook, Navajo Co., AZ
Tuba City, Coconino Co., AZ
Tucson, Pima Co., AZ
Yuma, Yuma Co., AZ
Yuma (35 mi E.), Yuma Co., AZ
Joshua Forest, Riverside Co., CA
Delta, Delta Co., CO
Guaymas, Mexico
Tularosa, Otero Co., NM
Bernalillo, Sandoval Co., NM
Adrian, Malheur Co., OR
Nyssa, Malheur Co., OR
Ephraim (Excel Canyon), Sanpete Co., UT
Sanpete Co., UT
Huntington, Emery Co., UT
Jericho Sand Dunes, Juab Co., UT
Jericho Sand Dunes (gigas), Juab Co., UT
Johnson Canyon, Kane Co., UT
Myton, Duchesne Co., UT
Douglas, Converse Co., WY

Table 58.—Physical and chemical properties of topsoil and subsoil by soil amendment treatment 6 years after treatment, Alton 8-acre study site

Properties	Topsoil-hay	Topsoil-compost	Topsoil-control	Subsoil-hay	Subsoil-compost	Subsoil-control
Sand (percent)	30	43	37	31	40	37
Silt (percent)	37	30	35	35	34	35
Clay (percent)	33	27	28	34	26	28
Saturation (percent)	52	55	50	46	46	46
CEC (meq/100 g)	20	22	26	15	19	14
NH_4OAc extractable						
Na (meq/100 g)	0.27	0.22	0.20	0.21	0.20	0.20
Ca (meq/100 g)	52	53	50	49	52	48
Water soluble cations						
Na (meq/100 g)	0.02	0.02	0.02	0.02	0.02	0.03
Ca (meq/100 g)	0.18	0.25	0.18	0.13	0.22	0.13
P; $NaHCO_3$ (ppm)	1.1	1.4	1.3	0.5	2.1	0.5
N; NO_3 (ppm)	0.8	1.2	0.9	0.9	1.1	1.4
ECe (mmhos/cm)	0.4	0.5	0.4	0.4	0.5	0.4
Na adsorption ratio	0.3	0.2	0.3	0.3	0.3	0.5
pH	7.8	7.9	7.8	7.8	8.0	8.0

Table 59.—Physical and chemical properties of carbonaceous shale overburden (clay loam) and three types of topsoil from the Alton coal field

Properties	Clay loam	Sandy loam topsoil	Loam topsoil	Silty clay topsoil
Bulk density	1.34	1.35	1.50	1.01
Sand (percent)	32	63	41	6
Silt (percent)	31	23	34	40
Clay (percent)	37	14	25	54
Saturation (percent)	56	26	36	59
Percent moisture at				
0.1 atm	31.3	19.8	25.7	36.4
0.33 atm	23.9	10.0	18.2	29.1
15 atm	15.3	4.3	9.0	15.9
Color (moist)	10 yr, 4/1	5 yr, 3/3	10 yr, 3/2	5 yr, 5/1
CEC (meq/100 g)	32.6	9.2	17.1	40.2
NH_4OAc extractable				
Na (meq/100 g)	0.5	0.2	0.3	1.3
Water soluble cations				
Na (meq/100 g)	0.2	≤ 0.1	≤ 0.1	0.2
Ca (meq/100 g)	1.4	0.1	0.2	0.1
Mg (meq/100 g)	1.7	≤ 0.1	0.1	≤ 0.1
K (meq/100 g)	≤ 0.1	≤ 0.1	0.1	≤ 0.1
Exch. Na (meq/100 g)	0.3	0.2	0.2	1.0
Exch. Na (percent)	1.0	2.0	1.0	3.0
Na adsorption ratio	0.5	0.8	0.6	3.1
$NaHCO_3$ - P (ppm)	31.0	16.0	12.0	0.6
NO_3 - N (ppm)	1.4	3.8	27.0	1.6
ECe (mmhos/cm)	3.3	0.6	1.1	0.6
pH	7.6	7.6	7.7	8.5

Table 60.—Physical and chemical properties of four soil materials on the Alton 3-acre study site

Properties	Sandy loam topsoil	Silty clay subsoil	Clay loam subsoil	Carbonaceous shale overburden
Sand (percent)	57	3	14	26
Silt (percent)	26	42	42	39
Clay (percent)	17	55	44	35
Saturation (percent)	44	71	81	46
CEC (meq/100 g)	19	29	48	17
NH_4OAc extractable				
Na (meq/100 g)	0.22	0.22	0.53	0.19
Ca (meq/100 g)	49	50	39	42
Water soluble cations				
Na (meq/100 g)	0.02	0.03	0.07	0.02
Ca (meq/100 g)	0.25	0.09	0.08	0.09
P; $NaHCO_3$ (ppm)	5.2	0.5	0.5	0.5
N; NO_3 (ppm)	4.0	1.0	0.8	0.4
ECe (mmhos/cm)	0.6	0.3	0.4	0.3
Na adsorption ratio	0.2	0.3	0.7	0.2
pH	7.9	8.3	8.3	8.0

Table 61.—Mean daily air and soil temperatures (°C) for each month from May 1979 through December 1982 at the town of Alton and the Alton 8-acre study area

Date	Alton	Study area: Air at 54"	Air at 12"	Soil at -2"	Soil at -8"
1979 May (18-31)	13.6	14.1	13.6		14.5
June	15.5	18.4	17.6		19.0
July	19.1	22.2	21.4		22.9
August	17.2	19.4	19.0		21.8
September	16.7	18.9	18.1		20.6
October	10.5	12.5	11.5		16.1
November	.6	1.2	.4		6.0
December	.6	.5	-.8		2.7
1980 January	-1.0	0	-.8		1.9
February	.3	2.5	-.1		1.7
March	-.7	1.5	0		1.4
April	5.8	7.9	7.7		7.6
May	9.0	10.0	9.7		11.2
June	15.1	18.4	17.2		18.5
July	19.1	21.2	20.5		21.6
August	17.2	20.1	19.7		22.2
September	14.5	17.1	16.6		18.9
October	9.1	10.0	9.2		13.0
November	4.0	4.9	3.9		6.3
December	3.4	4.2	3.3		3.9
1981 January	1.2	2.1	1.5		3.6
February	1.0	2.5	2.0		3.8
March	1.9	2.7	2.7		5.1
April	8.5	9.5	9.2		10.0
May	10.5	12.0	11.9		14.3
June	17.5	20.8	20.7		20.8
July	20.1	22.7	22.8	24.6	23.2
August	18.1	20.2	20.1	20.8	21.4
September	14.7	16.6	16.3	13.7	18.2
October	7.1	8.0	7.8	1.0	11.0
November	4.2	5.4	4.7	-4.0	6.7
December	1.1	1.9	1.3	-.3	3.0
1982 January	-3.5	-1.8	-3.3	.3	1.4
February	-1.0	.9	-.6	1.9	—
March	1.4	2.3	2.1	4.6	—
April	5.4	7.0	6.9	9.7	—
May	10.6	12.2	12.0	15.8	—
June	14.4	17.3	17.1	21.5	18.7
July	17.9	21.1	21.2	25.3	22.6
August	17.9	19.6	19.9	21.6	21.3
September	13.7	15.1	15.2	16.6	17.6
October	6.7	7.8	7.7	8.4	11.1
November	.9	1.9	1.6	2.2	5.2
December	-3.1	-.8	-1.9	-.6	2.9

Table 62.—Mean daily maximum air and soil temperatures (°C) for each month from May 1979 through December 1982 at the town of Alton and the Alton study area

	Date	Alton	Study area			
			Air at 54"	Air at 12"	Soil at −2"	Soil at −8"
1979	May (18–31)	22.7	22.8	24.4		15.6
	June	26.1	26.8	29.4		20.4
	July	29.4	31.6	35.4		24.3
	August	26.6	28.6	31.5		23.2
	September	26.7	28.5	32.3		21.8
	October	20.1	21.4	28.5		17.1
	November	8.3	8.8	11.4		6.6
	December	9.2	9.1	11.4		3.2
1980	January	4.6	6.6	4.5		1.9
	February	7.3	10.8	3.7		1.7
	March	6.4	8.8	5.4		1.7
	April	14.2	15.2	17.3		8.5
	May	17.2	16.9	18.8		11.8
	June	26.4	26.9	29.2		19.8
	July	28.6	30.4	33.9		22.9
	August	26.7	28.8	32.9		23.5
	September	23.6	25.7	29.5		19.1
	October	17.9	18.8	22.1		13.9
	November	12.8	14.0	18.0		7.0
	December	11.3	13.5	17.3		4.4
1981	January	9.8	10.8	14.7		4.2
	February	10.0	11.2	14.9		4.3
	March	8.9	9.6	12.7		5.7
	April	17.6	17.2	20.7		10.8
	May	19.2	19.5	23.2		15.3
	June	27.7	29.3	33.5		22.0
	July	29.4	31.4	35.8	36.6	24.3
	August	27.3	29.4	33.2	31.5	22.4
	September	23.7	25.2	28.7	24.6	19.1
	October	14.2	15.4	18.3	8.8	11.8
	November	12.0	13.1	15.8	2.4	7.3
	December	8.4	9.4	11.9	2.3	3.4
1982	January	3.8	6.0	5.3	.6	1.4
	February	6.8	9.3	8.9	4.1	—
	March	7.3	8.5	10.8	9.5	—
	April	14.1	14.4	17.6	16.6	—
	May	20.1	19.6	23.3	24.6	—
	June	25.0	25.8	30.7	33.2	20.1
	July	27.7	29.7	34.4	37.3	24.1
	August	25.8	28.5	32.9	31.1	22.9
	September	21.2	23.0	27.0	24.9	18.9
	October	15.4	15.8	19.9	16.2	12.2
	November	7.3	8.2	10.9	5.1	5.7
	December	3.5	6.9	7.2	−.1	3.0

Table 63.—Mean daily minimum air and soil temperatures (°C) for each month from May 1979 through December 1982 at the town of Alton and the Alton study area

Date		Alton	Study area			
			Air at 54"	Air at 12"	Soil at −2"	Soil at −8"
1979	May (18–31)	4.4	6.5	4.7		13.5
	June	4.9	9.0	6.1		17.6
	July	8.8	12.4	8.9		21.5
	August	7.7	11.0	7.9		20.6
	September	6.6	10.2	6.2		19.5
	October	.9	4.5	.2		15.1
	November	−7.1	−4.8	−8.8		5.5
	December	−8.1	−5.6	−9.6		2.2
1980	January	−6.6	−4.3	−4.7		1.6
	February	−6.8	−3.6	−2.7		1.7
	March	−7.9	−4.7	−5.1		1.2
	April	−2.6	1.0	−1.0		6.8
	May	.8	2.3	.8		10.4
	June	3.7	8.5	4.8		17.2
	July	9.6	12.2	9.6		20.4
	August	7.7	11.5	7.8		21.0
	September	5.3	8.8	5.2		17.8
	October	.3	2.4	−1.1		11.6
	November	−4.8	−2.3	−6.6		5.7
	December	−4.5	−2.3	−5.6		3.6
1981	January	−7.4	−4.4	−8.8		3.2
	February	−8.0	−4.8	−8.1		3.4
	March	−5.1	−3.0	−5.5		4.6
	April	−.6	1.7	−1.1		9.2
	May	1.7	4.4	1.7		13.5
	June	7.2	11.4	7.8		19.7
	July	10.7	14.4	11.3	15.3	22.2
	August	8.9	12.3	9.8	12.6	20.4
	September	5.7	9.5	6.8	5.9	17.3
	October	0	1.9	−.4	−4.3	10.4
	November	−3.6	−1.0	−3.8	−8.2	6.2
	December	−6.2	−4.3	−6.8	−2.0	2.8
1982	January	−10.8	−8.5	−10.8	.2	1.3
	February	−8.9	−5.6	−8.3	.5	—
	March	−4.5	−2.7	−4.7	1.8	—
	April	−3.2	−.7	−3.2	4.2	—
	May	1.2	4.3	1.2	8.6	—
	June	3.8	7.5	4.1	12.2	17.3
	July	8.1	12.2	8.9	15.8	21.0
	August	10.0	13.0	11.3	15.1	19.7
	September	6.2	8.7	6.8	10.8	16.4
	October	−2.1	.7	−2.0	2.8	9.9
	November	−5.5	−3.3	−5.3	.6	4.7
	December	−9.7	−6.5	−8.6	−1.1	2.8

Table 64.—Extreme temperatures (°C) for each month from May 1979 through December 1982, Alton 8-acre study area

		Air				Soil			
		At 54"		At 12"		At 2"		At 8"	
	Date	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
1979	May	27.2	1.5	28.9	.1			16.3	12.5
	June	34.0	.2	36.7	0			23.7	14.1
	July	35.3	7.5	39.7	4.5			26.1	19.6
	August	36.0	5.4	40.2	3.7			26.6	16.1
	September	33.1	4.8	37.5	.7			23.6	17.1
	October	29.1	-7.8	33.2	-12.3			20.2	8.9
	November	13.7	-12.0	16.6	-16.3			9.8	1.5
	December	17.4	-14.5	20.0	-20.6			5.2	.7
1980	January	15.7	-10.7	10.2	-11.3			2.5	.6
	February	18.6	-12.8	9.8	-10.6			2.1	1.1
	March	18.6	-11.0	12.2	-14.7			4.3	.8
	April	25.3	-5.9	27.3	-7.0			11.4	2.0
	May	26.4	-3.4	27.8	-5.2			14.6	7.8
	June	32.3	2.3	35.7	.1			23.3	12.6
	July	35.9	8.2	40.2	5.3			25.0	17.7
	August	35.2	5.9	39.6	2.3			25.8	17.8
	September	31.1	.7	36.2	-3.1			22.4	16.1
	October	31.8	-4.9	35.9	-9.3			20.2	6.2
	November	22.1	-11.7	25.7	-17.4			10.5	2.4
	December	23.0	-10.9	27.0	-12.5			5.8	2.2
1981	January	18.5	-17.4	23.1	-21.4			5.5	2.0
	February	20.0	-11.3	24.5	-14.0			6.8	1.8
	March	17.0	-8.8	20.8	-11.3			8.4	2.6
	April	24.1	-7.6	27.5	-11.1			14.3	5.6
	May	29.1	-2.9	32.9	-6.0			17.2	11.0
	June	35.9	.1	39.8	-2.8			25.3	14.7
	July	38.3	11.3	41.1	7.8	42.2	12.0	25.7	19.9
	August	37.9	6.4	42.0	5.5	42.8	7.8	26.7	17.5
	September	29.2	4.9	33.7	2.3	31.7	-.7	22.2	15.6
	October	24.6	-5.2	29.3	-9.2	20.4	-9.7	17.8	6.4
	November	21.9	-11.0	25.2	-13.5	8.0	-13.4	9.2	3.1
	December	18.1	-12.3	20.0	-14.9	8.9	-10.0	5.3	1.3
1982	January	17.1	-22.8	17.2	-27.4	3.7	-.2	1.8	1.1
	February	17.1	-20.7	18.8	-23.9	14.2	-.1	—	—
	March	15.0	-10.8	18.6	-12.9	14.9	-.3	—	—
	April	24.0	-10.2	27.0	-15.0	23.8	1.4	—	—
	May	25.2	-3.8	30.4	-5.7	32.0	3.9	—	—
	June	32.3	1.0	37.9	-2.0	40.1	8.0	23.4	15.4
	July	35.7	4.6	40.8	0	42.3	10.8	25.8	17.9
	August	32.6	9.4	37.8	7.0	36.2	10.7	25.4	17.8
	September	32.6	0	38.8	-1.7	32.8	4.4	24.2	11.6
	October	21.8	-6.7	26.6	-9.1	20.0	-.6	13.8	6.5
	November	17.7	-10.8	21.7	-13.8	11.0	-.8	9.1	3.2
	December	17.5	-15.5	16.7	-17.3	1.7	-6.9	4.0	1.0

Table 65.—Long-term means (1941 to 1970) of monthly temperature (°C) and precipitation (inches) for the town of Alton, Kane County, Utah

Month	Mean temperature	Mean precipitation
January	−2.7	1.90
February	−1.3	1.49
March	.7	1.48
April	5.7	1.25
May	10.3	.78
June	14.7	.64
July	19.0	1.43
August	18.1	1.94
September	14.4	1.23
October	9.0	1.19
November	2.7	1.26
December	−1.4	1.79
Annual mean	7.4	16.38

Table 66.—Miscellaneous microclimatic data from the Alton study area

Item	1979	1980	1981	1982
Length of frost-free period at 54″	156	141	147	141
Length of frost-free period at 12″	118	113	115	96
Length of frost-free period at Alton (NOAA)	124	108	114	91
No. days 0 °C, or lower, at 54″ (5/1–10/31)	6	19	17	16
No. days 0 °C, or lower, at 12″ (5/1–10/31)	11	34	32	34
Extreme min. temp. at 54″ (5/1–10/31), °C	−7.8	−4.9	−5.2	−6.7
Extreme min. temp. at 12″ (5/1–10/31), °C	−12.3	−9.3	−9.2	−9.1
No. days ≥32 °C at 54″	31	23	27	14
No. days ≥32 °C at 12″	74	56	76	62
Extreme max. temp. at 54″, °C	36.0	35.9	38.3	35.7
Extreme max. temp. at 12″, °C	40.0	40.2	42.0	40.8
Dates between which mean daily soil	?	4/19	4/10	—
temp. at 8 inches = 10 °C or higher	10/31	10/22	10/22	10/27
Max. rainfall in 1 hour (inch)	0.21	0.46	0.22	0.73
Max. rainfall in 24 hours (inch)	0.66	0.66	0.69	0.82
Max. rainfall in 7 days (inch)	1.20	1.14	1.40	1.48
Max. consecutive days with no recorded rainfall ≥0.25 inches (5/1–10/31)	79	46	45	91
Max. consecutive days no recorded rain	18	17	28	26

Table 67.—Cumulative "growing degree days" at the Alton 8-acre study site, 1979 to 1982

Week beginning		1979	1980	1981	1982
Jan.	3	2	6	31	7
	17	7	27	98	31
	31	7	76	120	63
Feb.	14	32	104	179	107
Mar.	1	51	152	220	161
	15	84	209	263	193
	29	108	231	319	230
Apr.	12	176	317	424	306
	26	276	420	552	400
May	10	378	505	660	487
	24	512	616	784	639
June	7	681	772	979	787
	21	858	959	1,180	974
July	5	1,063	1,155	1,410	1,169
	19	1,284	1,369	1,634	1,388
Aug.	2	1,507	1,595	1,860	1,600
	16	1,683	1,811	2,051	1,822
	30	1,882	2,000	2,262	2,032
Sept.	13	2,083	2,189	2,437	2,184
	27	2,273	2,368	2,603	2,324
Oct.	11	2,438	2,498	2,680	2,415
	25	2,523	2,574	2,771	2,496
Nov.	8	2,567	2,674	2,862	2,540
	22	2,597	2,723	2,916	2,568
Dec.	6	2,650	2,769	2,969	2,602
	20	2,690	2,854	3,005	2,627
	27	2,701	2,899	3,009	2,629

Table 68.—Precipitation (inches) received at the town of Alton from October 1976 through September 1982, and at the 8-acre study site from May 1979 through September 1982

		Alton	Study area		Alton	Study area
1976				Oct.	.72	—
				Nov.	.15	—
				Dec.	.05	—
1977	Jan.	1.00	—	July	2.38	—
	Feb.	.03	—	Aug.	1.64	—
	Mar.	.20	—	Sept.	.96	—
	Apr.	.05	—	Oct.	1.02	—
	May	2.34	—	Nov.	.16	—
	June	.40	—	Dec.	1.35	—
				TOTAL	11.53	
1978	Jan.	2.65	—	July	.33	—
	Feb.	2.19	—	Aug.	.70	—
	Mar.	4.38	—	Sept.	1.39	—
	Apr.	2.04	—	Oct.	.83	—
	May	.60	—	Nov.	5.72	—
	June	0	—	Dec.	3.25	—
				TOTAL	24.08	
1979	Jan.	3.25	—	July	.34	.46
	Feb.	2.45	—	Aug.	1.55	1.46
	Mar.	3.78	—	Sept.	.11	.29
	Apr.	.02	—	Oct.	.41	.55
	May	1.02	[1].82	Nov.	.71	.97
	June	0	.11	Dec.	.53	.55
				TOTAL	14.17	—
1980	Jan.	6.38	4.56	July	2.41	1.32
	Feb.	4.48	7.47	Aug.	1.69	.75
	Mar.	1.86	2.28	Sept.	2.85	1.44
	Apr.	.88	.60	Oct.	1.31	.91
	May	1.72	1.32	Nov.	.11	.10
	June	.01	.27	Dec.	.23	.46
				TOTAL	23.93	21.48
1981	Jan.	.40	.12	July	.78	.66
	Feb.	.37	.72	Aug.	2.43	2.11
	Mar.	2.47	3.27	Sept.	1.22	1.53
	Apr.	1.13	1.08	Oct.	2.85	1.39
	May	.91	1.72	Nov.	1.48	.28
	June	.35	.12	Dec.	.06	.49
				TOTAL	14.45	13.49
1982	Jan.	2.46	1.62	July	1.27	.32
	Feb.	.85	.57	Aug.	2.71	1.35
	Mar.	2.44	3.55	Sept.	2.65	2.82
	Apr.	.71	.61	Oct.	1.09	.78
	May	.53	.68	Nov.	4.30	2.83
	June	.12	.22	Dec.	1.96	2.08
				TOTAL	21.09	17.43

[1]Data for May 19–31 only.

Table 69.—List of plant symbols used in figures and tables

Symbol	Scientific name	Common name
ACLA	*Achillea lanulosa*	Western yarrow
AGCR	*Agropyron cristatum*	Fairway crested wheatgrass
AGCR(H)	*A. cristatum*	Crested wheatgrass hybrid
AGCR(R)	*A. cristatum*	Rhizomatous crested wheatgrass
AGDE	*A. desertorum*	Standard crested wheatgrass
AGEL	*A. elongatum*	Tall wheatgrass
AGIN	*A. inerme*	Beardless bluebunch wheatgrass
AGIN[2]	*A. intermedium*	Intermediate wheatgrass
AGRI	*A. riparium*	Streambank wheatgrass
AGSM	*A. smithii*	Western wheatgrass
AGSP x AGRE	*A. spicatum* x *A. repens* hybrid	
AGTR[2]	*A. tricophorum*	Pubescent wheatgrass
AMFR	*Amorpha fruticosa*	Indigobush
AMUT	*Amelanchier utahensis*	Utah serviceberry
ARFI	*Artemisia filifolia*	Sand sagebrush
ARNO	*A. nova*	Black sagebrush
ARTR	*A. tridentata vaseyana*	Mountain big sagebrush
ASGL	*Astragalus globiceps*	Milkvetch
ATAP	*Atriplex aptera*	Shortwing saltbush
ATBO	*A. bonnevillensis*	Bonneville saltbush
ATCA	*A. canescens*	Fourwing saltbush
ATCA x ATCU	*A. canescens* x *A. cuneata* hybrid	
ATCA x ATID	*A. canescens* x *A. idahoensis*[1] hybrid	
ATCA x ATOB	*A. canescens* x *A. obovata* hybrid	
ATCA x ATTR	*A. canescens* x *A. tridentata* hybrid	
ATCA x ATCO x ATCA	*A. canescens* x *A. confertifolia* x *A. canescens* hybrid	
ATCOR x ATCU	*A. corrugata* x *A. cuneata* hybrid	
ATFA	*A. falcata*	Falcate saltbush
ATGA	*A. gardneri*	Gardner saltbush
ATID	*A. idahoensis*[1]	Idaho saltbush
ATLA	*A. lahontanensis*[1]	Lahontan saltbush
ATNA	*A. navajoensis*	Navajo saltbush
ATOB	*A. obovata*	Broadscale saltbush
ATRO	*A. robusta*[1]	
ATTO	*A. tooelensis*[1]	
ATTR	*A. tridentata*	Trident saltbush
ATTR x ATBO	*A. tridentata* x *A. bonnevillensis* hybrid	
BEFR	*Berberis fremontii*	Fremont barberry
BOGR	*Bouteloua gracilis*	Blue grama
BRIN	*Bromus inermis*	Smooth brome
CAAR	*Caragana arborescens*	Siberian peashrub
CAMO	*Camphorosma monspeliaca*	Mediterranean camphorfume
CECU	*Ceanothus cuneatus*	Wedgeleaf ceanothus
CELE[2]	*C. lemmoni*	Lemmon's ceanothus
CELA	*Ceratoides lanata*	Winterfat
CEPA	*C. papposa*	Plumed whitesage
CEBE	*Cercocarpus betuloides*	Birchleaf cercocarpus
CELE	*C. ledifolius*	Curlleaf cercocarpus
CEMO	*C. montanus*	Alderleaf cercocarpus
CHNA	*Chrysothamnus nauseosus*	Rubber rabbitbrush
COST	*Cowania stansburiana*	Cliffrose
CUNE	*Cupressus nevadensis*	Piute cypress
ELAN	*Elaeagnus angustifolia*	Russian-olive
ELCI	*Elymus cinereus*	Great Basin wildrye
ELJU	*E. junceus*	Russian wildrye
EPNE	*Ephedra nevadensis*	Nevada ephedra
EPVI	*E. viridis*	Green ephedra
ERCO	*Eriogonum corymbosum*	Corymbed eriogonum
FAPA	*Fallugia paradoxa*	Apacheplume
FRVE	*Fraxinus velutina*	Velvet ash

[1]Undescribed taxa provided by Dr. Howard Stutz.

(con.)

Table 69.—(con.)

Symbol	Scientific name	Common name
GRSP	*Grayia spinosa*	Spiny hopsage
HEBO	*Hedysarum boreale*	Utah sweetvetch
HIJA	*Hilaria jamesii*	Galleta
JUHO	*Juniperus horizontalis*	Creeping juniper
KOPR	*Kochia prostrata*	Prostrate summercypress
KOVI	*K. prostrata villosissima*	Villous prostrate summercypress
LOTA	*Lonicera tatarica*	Tatarian honeysuckle
MEME	*Medicago media*	'Drylander' alfalfa
ORHY	*Oryzopsis hymenoides*	Indian ricegrass
PEPA	*Penstemon palmeri*	Palmer penstemon
PEVE	*P. venustus*	Beautiful penstemon
PERA	*Peraphyllum ramosissimum*	Squawapple
POFR	*Potentilla fruticosa*	Shrubby cinquefoil
POPLAR	*Populus* spp.	Hybrid poplar
PRVI	*Prunus virginiana*	Western black chokecherry
PUGL	*Purshia glandulosa*	Desert bitterbrush
PUTR	*P. tridentata*	Antelope bitterbrush
QUGA	*Quercus gambelii*	Gambel oak
RHTR	*Rhus trilobata*	Skunkbush
RIAU	*Ribes aureum*	Golden currant
ROWO	*Rosa woodsii*	Wood's rose
SACE	*Sambucus cerulea*	Blueberry elder
SHRO	*Shepherdia rotundifolia*	Roundleaf buffaloberry
SIHY	*Sitanion hystrix*	Squirreltail
SPCO	*Sphaeralcea coccinea*	Common globemallow
SPGR	*S. grossulariaefolia*	Gooseberryleaf globemallow
SPPA	*S. parvifolia*	Nelson globemallow
SPAI	*Sporobolus airoides*	Alkali sacaton
SPCR	*S. cryptandrus*	Sand dropseed
STCO	*Stipa comata*	Needle-and-thread
YUCCA	*Yucca* spp.	Yucca

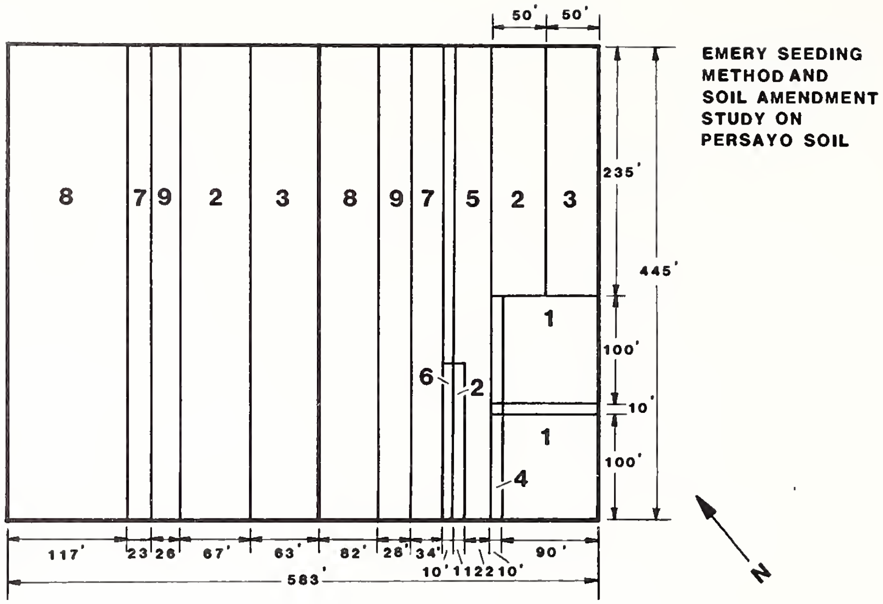

Figure 41.—Field plot design for the study of alternative site preparation methods and organic soil amandments on the Persayo soil series, Emery, Utah.

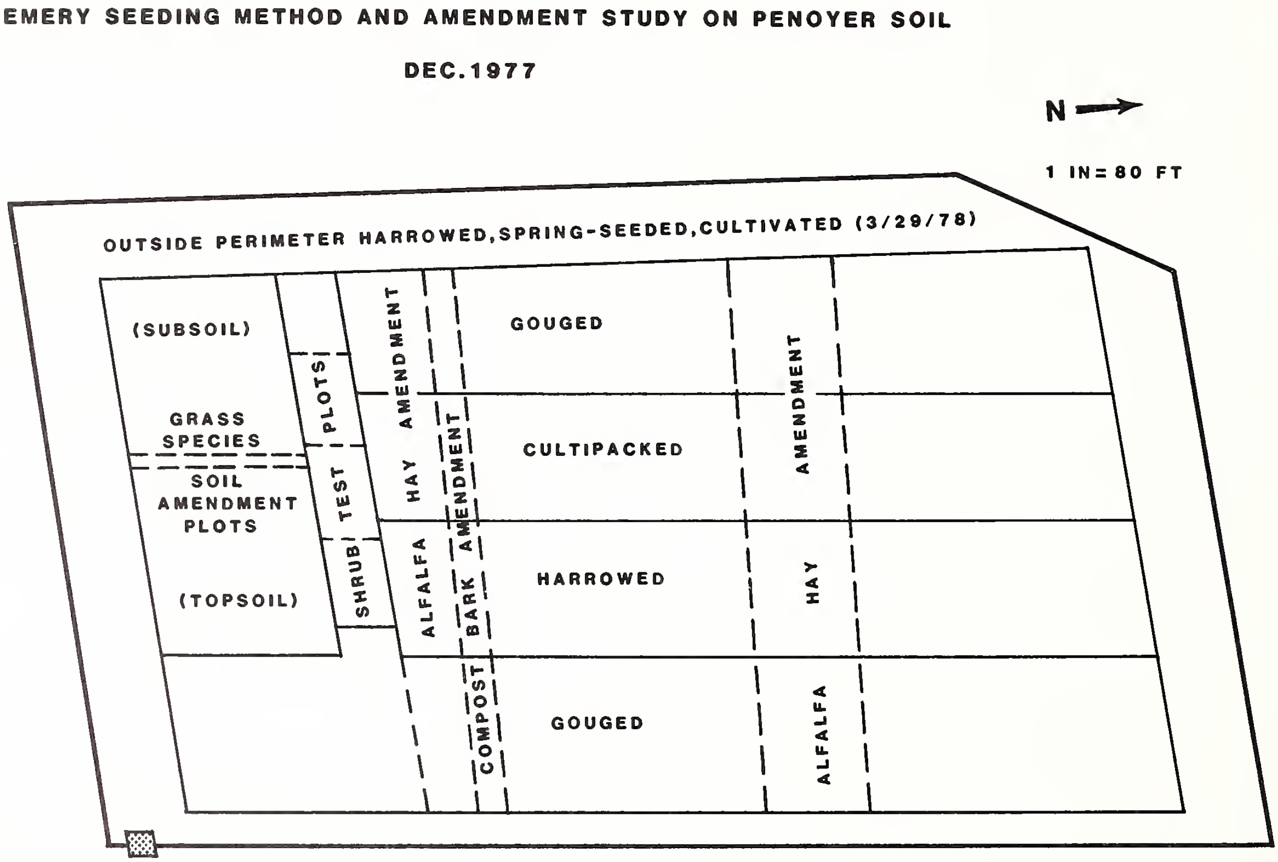

Figure 42.—Field plot design for the study of alternative site preparation methods and organic soil amendments on the Penoyer soil series, Emery, Utah.

90'

15'

10'

100'

SOIL
AMENDMENTS

200 & 600 ALFALFA HAY

300 & 500 COMPOST

100 & 400 CONTROL

BLOCK I (TOPSOIL)

100	200	300	400	500	600
AGCRFA	ORHY	AGCRH	ORHY	SPAI	ELJU
AGCRH	SPAI	PEPA	AGCRFA	SIHY	AGCRFA
AGDENO	SIHY	ELJU	AGDENO	BOGR	PEPA
BOGR	SPCR	SPAI	SPCR	AGDENO	AGDENO
ELJU	AGCRFA	SPCR	PEPA	AGCRH	SPCR
SPAI	PEPA	SIHY	ELJU	PEPA	SIHY
SPCR	ELJU	BOGR	AGCRH	ORHY	SPAI
ORHY	AGCRH	AGDENO	BOGR	AGCRFA	ORHY
SIHY	BOGR	AGCRFA	SIHY	ELJU	BOGR
PEPA	AGDENO	ORHY	SPAI	SPCR	AGCRH

10'

MEDIAN STRIP

100'

BLOCK II (SUBSOIL)

100	200	300	400	500	600
AGCRH	SPCR	AGCRFA	AGDENO	BOGR	ELJU
AGCRFA	AGCRH	ORHY	SIHY	SPAI	AGCRH
PEPA	AGDENO	AGCRH	BOGR	AGDENO	BOGR
ORHY	SPAI	PEPA	SPAI	ORHY	AGDENO
ELJU	BOGR	BOGR	ELJU	SPCR	SPAI
BOGR	ORHY	SPAI	SPCR	PEPA	SPCR
SIHY	ELJU	SIHY	AGCRFA	AGCRH	SIHY
SPCR	AGCRFA	SPCR	AGCRH	SIHY	AGCRFA
SPAI	PEPA	AGDENO	PEPA	AGCRFA	PEPA
AGDENO	SIHY	ELJU	ORHY	ELJU	ORHY

REP. II (100–300) — REP. I (400–600)

N

Figure 43.—Field plot design for the evaluation of organic soil amendments and different herbaceous species on the Persayo soil series, Emery, Utah.

90'

15'

SOIL
AMENDMENTS

100 & 500 ALFALFA HAY

200 & 400 COMPOST

300 & 600 CONTROL

N →

	100	200	300	400	500	600	
BLOCK I (TOPSOIL) 100'	BOGR	ELJU	BOGR	AGCRFA	AGDENO	SPAI	1
	PEPA	AGCRFA	AGCRFA	SPCR	ELJU	SPCR	2
	AGCRH	AGDENO	SPAI	BOGR	PEPA	BOGR	3
	SPCR	BOGR	PEPA	PEPA	SPCR	AGCRFA	4
	SIHY	SPAI	AGCRH	AGCRH	SIHY	SPAI	5
	ORHY	AGCRH	SIHY	AGDENO	BOGR	AGDENO	6
	ELJU	PEPA	ORHY	ELJU	AGCRFA	ELJU	7
	SPAI	SIHY	AGDENO	ORHY	AGCRH	AGCRH	8
	AGCRFA	ORHY	SPCR	BOGR	SPAI	SIHY	9
	AGDENO	SPCR	ELJU	SIHY	ORHY	PEPA	10
10'	HIJA	HIJA	HIJA		HIJA		
BLOCK II (SUBSOIL) 100'	BOGR	AGCRFA	PEPA	ORHY	BOGR	ORHY	11
	SIHY	SPAI	SPCR	ELJU	PEPA	AGCRH	12
	AGDENO	SIHY	AGCRH	SPAI	SIHY	AGDENO	13
	PEPA	ELJU	ORHY	AGDENO	AGCRFA	ELJU	14
	SPAI	AGCRH	ELJU	AGCRFA	SPAI	PEPA	15
	ELJU	SPCR	SIHY	PEPA	AGDENO	ORHY	16
	ORHY	BOGR	BOGR	AGCRH	AGCRH	SIHY	17
	SPCR	AGDENO	AGCRFA	BOGR	ELJU	SPCR	18
	AGCRH	PEPA	AGDENO	SIHY	SPCR	AGCRFA	19
	AGCRFA	ORHY	SPAI	SPCR	ORHY	BOGR	20

Each plot row: 10'

REP. II (100–300) | REP. I (400–600)

Figure 44.—Field plot design for the evaluation of organic soil amendments and different herbaceous species on the Penoyer soil series, Emery, Utah.

60'

Block #2 | Block #4

24'

KOPR 4	CELA	ATCA	ARNO	ATTR	KOPR 11	ATTO	EPNE	CAMO	ERCO
ATRO	ATTO	ATAP	ATGA	ERCO	ATOB	GRSP	ATRO	ATGA	ATAP
ATOB	KOPR 12	EPNE	GRSP	CAMO	ATID	ATCA X ATCU	ARNO	ATTR	KOPR 12
KOPR 11	ATID	ATCA X ATCU	ATNA	ATBO	KOPR 14	ATNA	ATBO	CELA	ATCA
ARNO	ATBO	ATAP	ATTR	ERCO	ATRO	CAMO	KOPR 12	ERCO	ATID
ATGA	KOPR 12	ATCA	KOPR 4	ATNA	ATCA	ATTR	EPNE	ATNA	ATOB
CELA	ATRO	ATTO	ATID	GRSP	KOPR 11	ARNO	ATTO	ATAP	KOPR 4
EPNE	ATOB	KOPR 11	ATCA X ATCU	CAMO	CELA	ATBO	GRSP	ATGA	ATCA X ATCU

N

Block #1 | Block #3

Figure 45.—Field plot design for testing shrub adaptability on Persayo soil, Emery coal field. See appendix table 69 for plant symbol key.

SUBSOIL | TOPSOIL

BLOCK #4 | BLOCK #3 | BLOCK #2 | BLOCK #1

30'

ATBO	ARNO	ATCA	ATCA X ATIO	CEPA	KOPR #9	ATAP	ATOB	KOPR 7	ERCO	ATNA X ATTO	ATRO ATCA X TR	ATGA	CEPA	CAMO	ATRO ATTO
ATTR	GRSP	ERCO	ATAP	KOVI	ATBO	ATCA X ATID	ATCA	ATCA X ATCU	EPNE	ARNO	CEPA	EPNE	ATTR	KOPR #9	ATCA X TR ATNA
KOVI	ATOB	EPNE	ATCA X TR ATTO	GRSP	ATTR	ATRO X ATTO	ATNA ATCA X TR	ATTR	ATCA	KOPR #9	CELA	ARNO	ATOB	CELA	ERCO
KOPR #7	CELA	KOPR #9	ATNA X ATRO	CELA	ATCA X ATCU	KOPR #7	CAMO	ATBO	ATGA	ATOB	ATCA X ATID	GRSP	ATCA	KOVI	KOPR #7
ATCA X ATCU	CEPA	ATGA	CAMO	ARNO	EPNE	ATGA	ERCO	KOVI	GRSP	CAMO	ATAP	ATBO	ATCA X ATCU	ATAP	ATCA X ATID

48'

N

Figure 46.—Field plot design for testing shrub adaptability on Penoyer soil, Emery coal field. See appendix table 69 for plant symbol key.

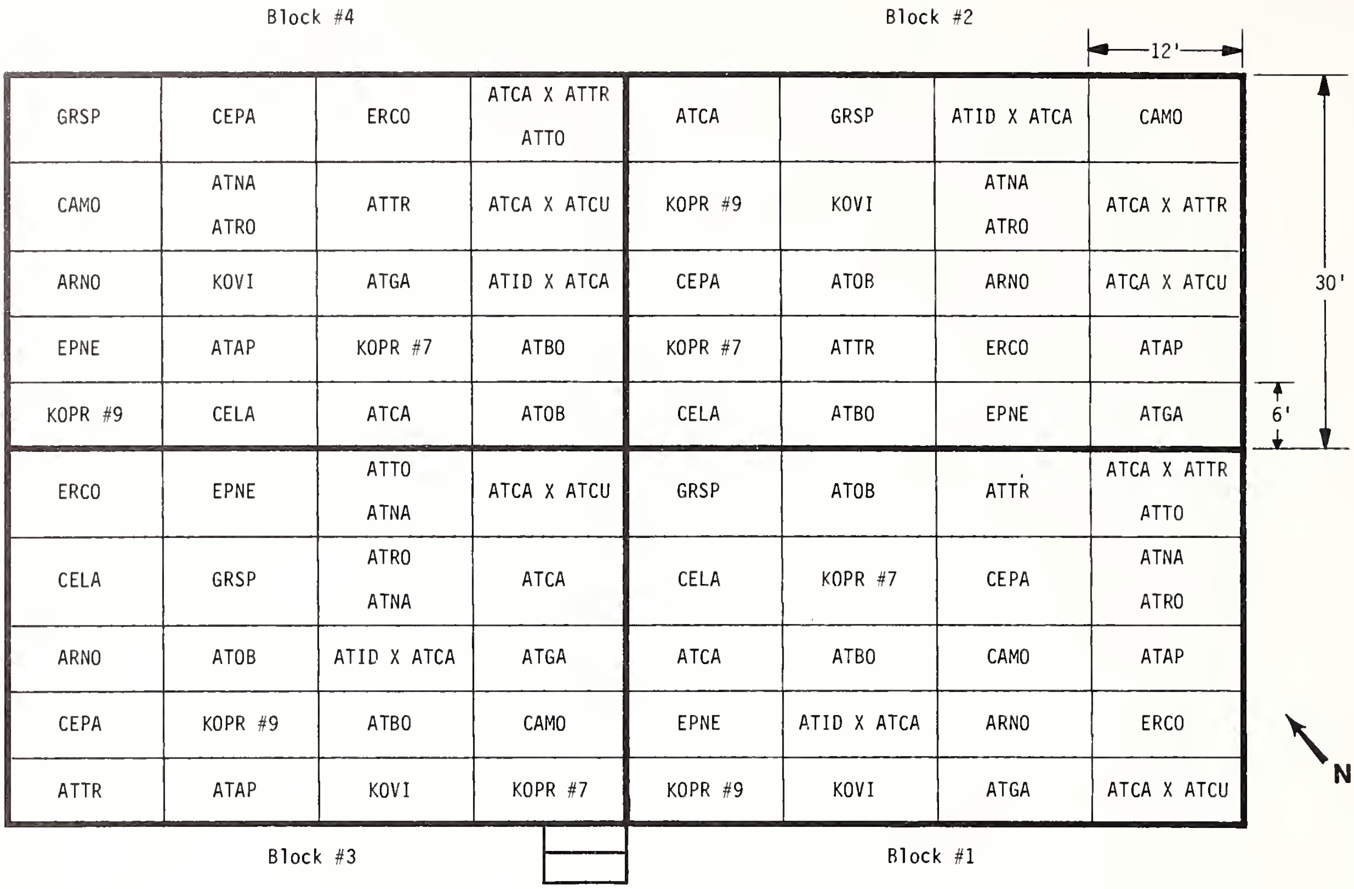

Figure 47.—Field plot design for testing shrub adaptability on shaley subsoil, Emery coal field. See appendix table 69 for plant symbol key.

Block					
BLOCK I	ATOB	ATTO	ATRO	ATCA X ATCU	CAMO
	ATGA	KOVI	CELA	EPNE	KOPR 12
	ARNO	GRSP	ATBO	ATTR	ATCA X ATTR
	ATCA	ATNA	ATAP	KOPR 11	ATID
BLOCK II	KOPR 11	EPNE	GRSP	ATRO	KOPR 12
	ATCA X ATCU	ARNO	ATCA	ATTR	ATID
	ATCA X ATTR	KOVI	ATGA	ATNA	ATTO
	CAMO	ATBO	CELA	ATAP	ATOB

Block		
BLOCK III	ARNO	ATNA
	ATTO	ATAP
	ATTR	ATOB
	ATBO	CELA
	EPNE	GRSP
	ATCA X ATTR	ATRO
	ATID	KOPR 11
	KOPR 4	ATCA X ATCU
	CAMO	KOPR 12
	ATGA	ATCA
BLOCK IV	ATBO	ATAP
	CELA	EPNE
	KOPR 11	ATOB
	ATRO	KOPR 4
	ATCA X ATCU	ATNA
	ATID	KOPR 12
	CEPA	ATGA
	ATCA	ATTR
	ATCA X ATTR	CAMO
	ARNO	ATTO

N

60'

24'

Figure 48.—Field plot design for testing shrub adaptability on Castle Valley soil series, Emery coal field. See appendix table 69 for plant symbol key.

N

24' · 60'

ATOB	ATID	KOPR 12	CEPA	ATTR	ATCA	ATTR X ATID	ATCA X ATCU
KOPR 7	ATBO	ATGA	KOPR 4	CELA	CAMO	ATRO	ATCA X ATTR
CAMO	ATCA X ATID	ATTR X ATCA	ATRO		ATOB	ATAP	CELA
ATTR	CEPA		ATCA X ATID		KOPR 4	KOPR 7	
KOPR 4	ATAP	ATCA		ATAP		KOPR 12	ATCA
ATCA X ATCU	ATTR X ATCA	ATBO	ATAP	ATCA X ATID	ATCA X ATTR	ATOB	KOPR 4
CELA		KOPR 7	ATTR	CEPA	KOPR 12		ATTR
	ATCA	CELA	ATOB	ATRO	ATCA X ATCU	CAMO	ATGA
ATRO	ATGA		ATCA X ATCU	ATBO	ATID	ATBO	ATID
KOPR 12		CAMO	ATID	ATGA	KOPR 7		CEPA
Block #4		Block #3		Block #2		Block #1	

Figure 49.—Field plot design for testing shrub adaptability on Blue Gate shale soil, Emery coal field. See appendix table 69 for plant symbol key.

N

12' · 42'

ATCA X ATTR	ATCA X ATID	ATCA	CEPA		ATCA		ATCA X ATCO X ATCA
ATCA X ATOB				ATRO		ATLA	ATCA
	ATLA	ATBO X ATTR	ATLA		ATCA	CEPA	ATCA X ATTR
	ATRO	ATCA X ATTR	ATRO	ATLA	CEPA		6'
CEPA	ATCA	ATCA	ATCA X ATCO X ATCA		ATCA X ATOB	ATBO X ATTR	ATCA X ATID
ATBO X ATTR	ATCA	ATFA	ATCA X ATID	ATBO X ATTR	ATCA X ATID	ATRO	ATCA
ATCA X ATCO X ATCA	ATFA	ATCA X ATOB		ATCA X ATCO X ATCA	ATCA X ATTR		ATCA X ATOB
Block #4		Block #3		Block #2		Block #1	

Figure 50.—Field plot design for testing Atriplex *accessions on Persayo soil, Emery coal field. See appendix table 69 for plant symbol key.*

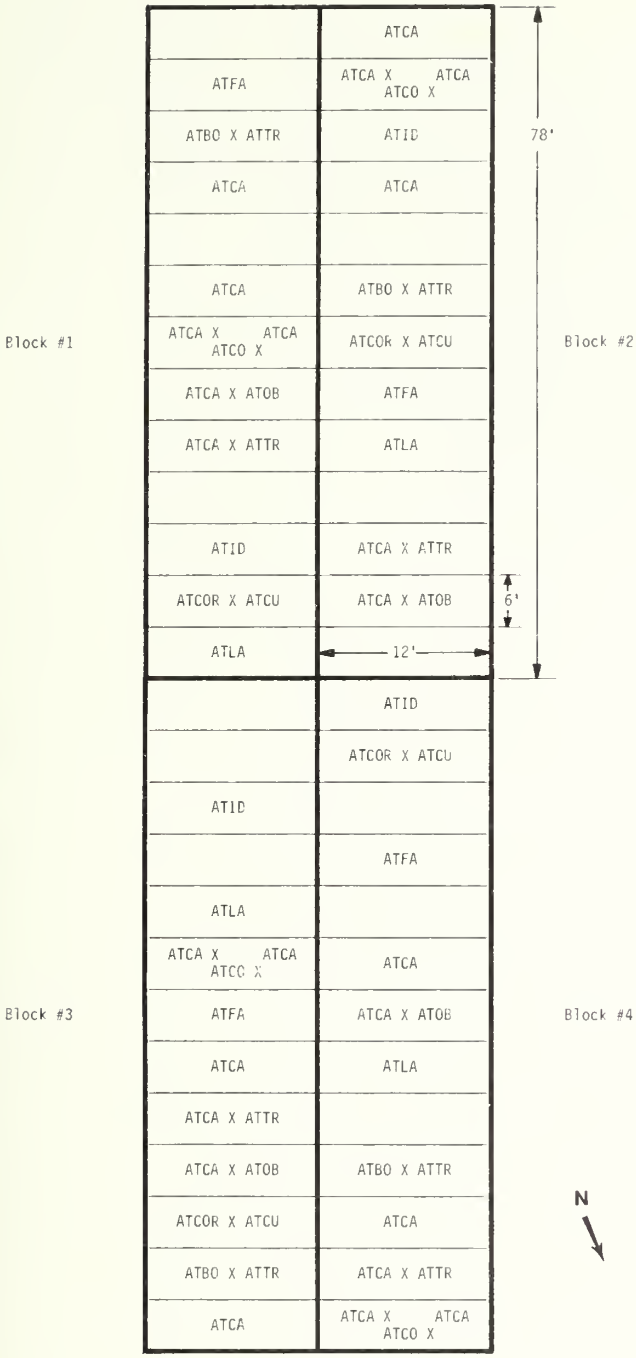

Figure 51.—Field plot design for testing Atriplex *accessions on Castle Valley soil, Emery coal field. See appendix table 69 for plant symbol key.*

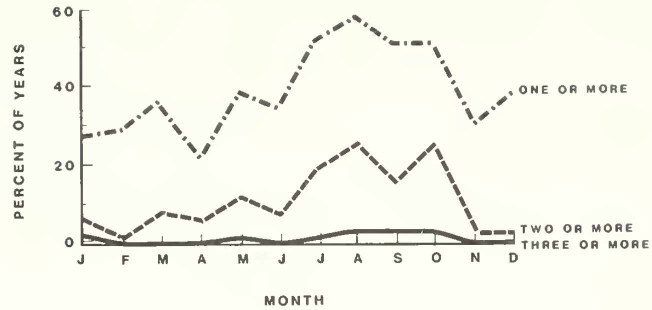

Figure 52.—Percent of past years in which each month had one or more, two or more, and three or more precipitation events of 0.4 inch or greater, Emery, Utah, 1922 to 1979.

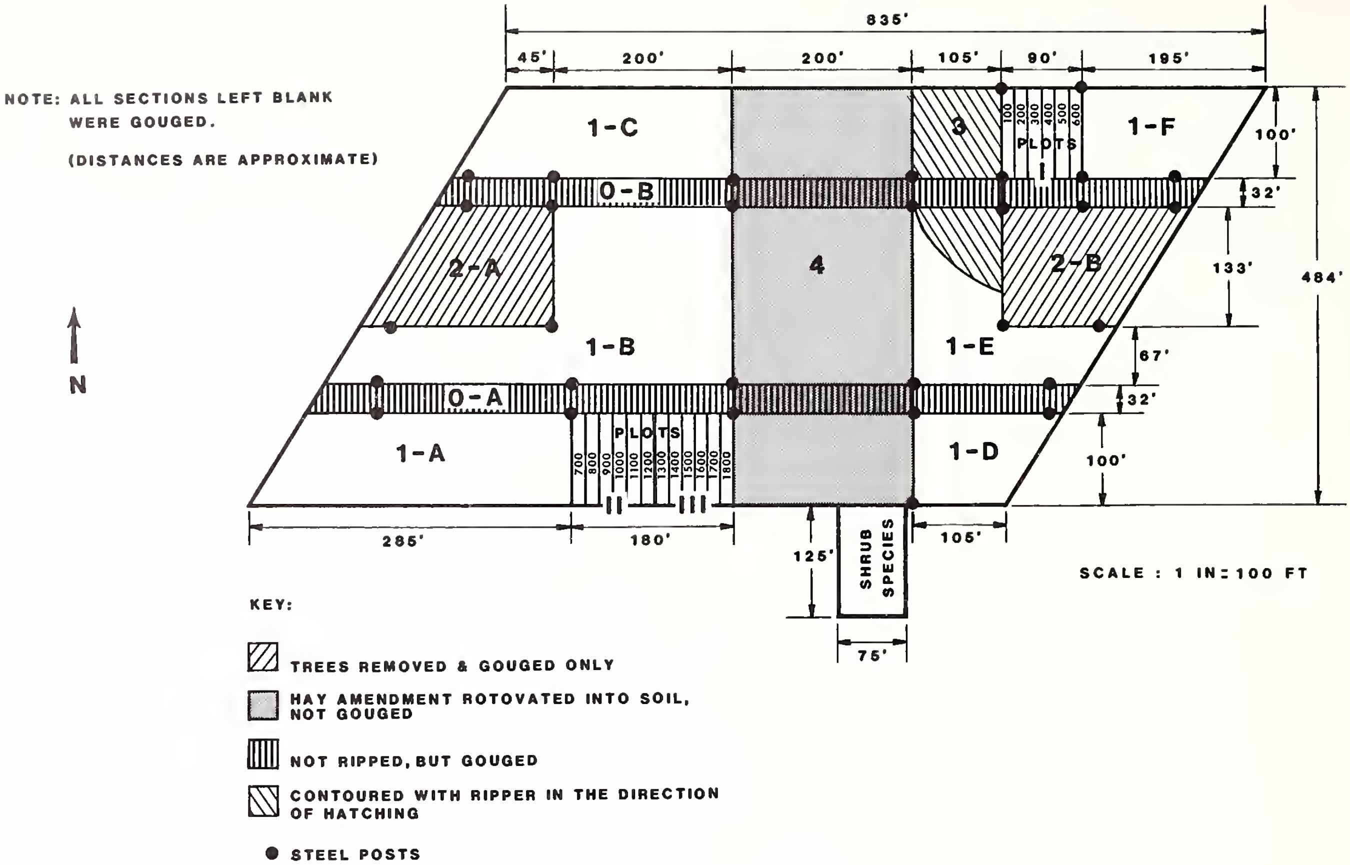

Figure 53.—Field plot design for the study of alternative site preparation methods on the 8-acre study site, Alton coal field.

Upper hillside block. Seeded Dec. 7, 1976

BLOCK I

100	200	300	400	500	600
AGRI	ELJU	AGSM	AGIN²	AGTR²	AGEL
AGIN²	BRIN	ELCI	AGEL	AGEL	AGCR
AGEL	AGTR²	AGRI	AGCR	AGCR	ELCI
ELJU	AGCR	ELJU	AGIN	AGSM	AGTR²
AGIN	AGSM	AGTR²	AGSM	AGIN	AGSM
ELCI	AGEL	BRIN	AGRI	AGRI	BRIN
BRIN	AGRI	AGEL	ELCI	ELCI	AGRI
AGCR	ELCI	AGCR	AGTR²	AGTR²	ELJU
AGSM	AGIN	AGIN²	BRIN	BRIN	AGIN²
AGTR²	AGIN²	AGIN	ELJU	ELJU	AGIN

Main Plot Treatments

BLOCKS	I	II	III
Topsoil (check)	500	800	1700
Topsoil + hay amendment	100	700	1800
" + compost amendment	300	1000	1400
Subsoil (check)	200	900	1600
Subsoil + hay amendment	600	1200	1500
" + compost amendment	400	1100	1300

Subplot Species Symbols

AGCR	*Agropyron cristatum* (Fairway)
AGEL	*Agropyron elongatum*
AGIN	*Agropyron inerme* (Whitmar)
AGIN²	*Agropyron intermedium*
AGRI	*Agropyron riparium* (Sodar)
AGSM	*Agropyron smithii*
AGTR²	*Agropyron trichophorum* (Luna)
BRIN	*Bromus inermis*
ELCI	*Elymus cinereus*
ELJU	*Elymus junceus*

Lower hillside blocks. Seeded Dec. 7, 1976

BLOCK II						BLOCK III					
700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800
ELJU	AGCR	ELJU	BRIN	AGCR	AGRI	AGRI	AGCR	ELJU	AGRI	AGTR²	ELCI
AGCR	AGRI	AGSM	ELJU	ELJU	AGEL	AGIN	AGEL	ELCI	AGEL	ELJU	AGEL
AGSM	AGEL	BRIN	AGCR	BRIN	AGTR²	AGCR	AGRI	AGSM	AGIN²	AGIN	AGTR²
AGTR²	ELJU	AGIN	AGIN	ELCI	ELCI	AGTR²	BRIN	AGEL	AGSM	AGIN	AGCR
AGRI	AGIN	AGCR	AGEL	AGTR²	BRIN	ELCI	AGIN	AGTR²	ELCI	AGCR	AGIN
AGIN²	BRIN	AGRI	AGSM	AGIN	AGSM	AGEL	ELJU	AGCR	ELJU	BRIN	AGSM
AGIN	ELCI	AGTR²	AGRI	AGRI	ELJU	ELJU	AGSM	AGRI	BRIN	ELCI	BRIN
AGEL	AGTR²	AGIN²	AGTR²	AGIN²	AGIN	BRIN	AGTR²	AGIN	AGCR	AGRI	AGIN
BRIN	AGIN	AGEL	ELCI	AGSM	AGCR	AGIN²	ELCI	AGIN²	AGTR²	AGEL	ELJU
ELCI	AGSM	ELCI	AGIN²	AGEL	AGIN²	AGSM	AGIN²	BRIN	AGIN	AGSM	AGRI

Figure 54.—Field plot design for the evaluation of organic soil amendments and different grass species on the 8-acre study site, Alton coal field. See appendix table 69 for plant symbol key.

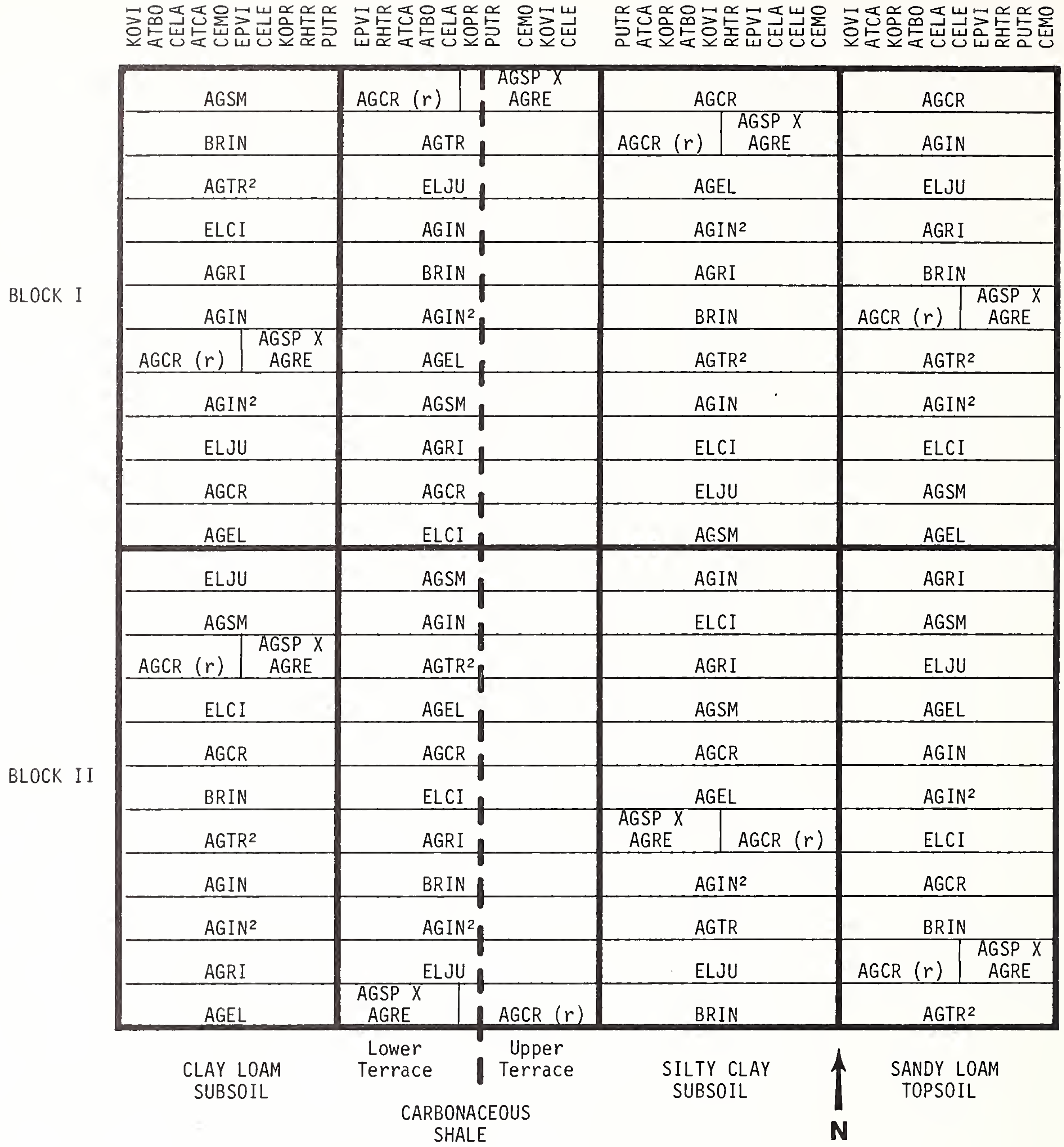

Figure 55.—Field plot design for the study of grass species establishment and growth, and shrub survival and growth, on four soil materials at the 3-acre study site, Alton coal field. See appendix table 69 for plant symbol key.

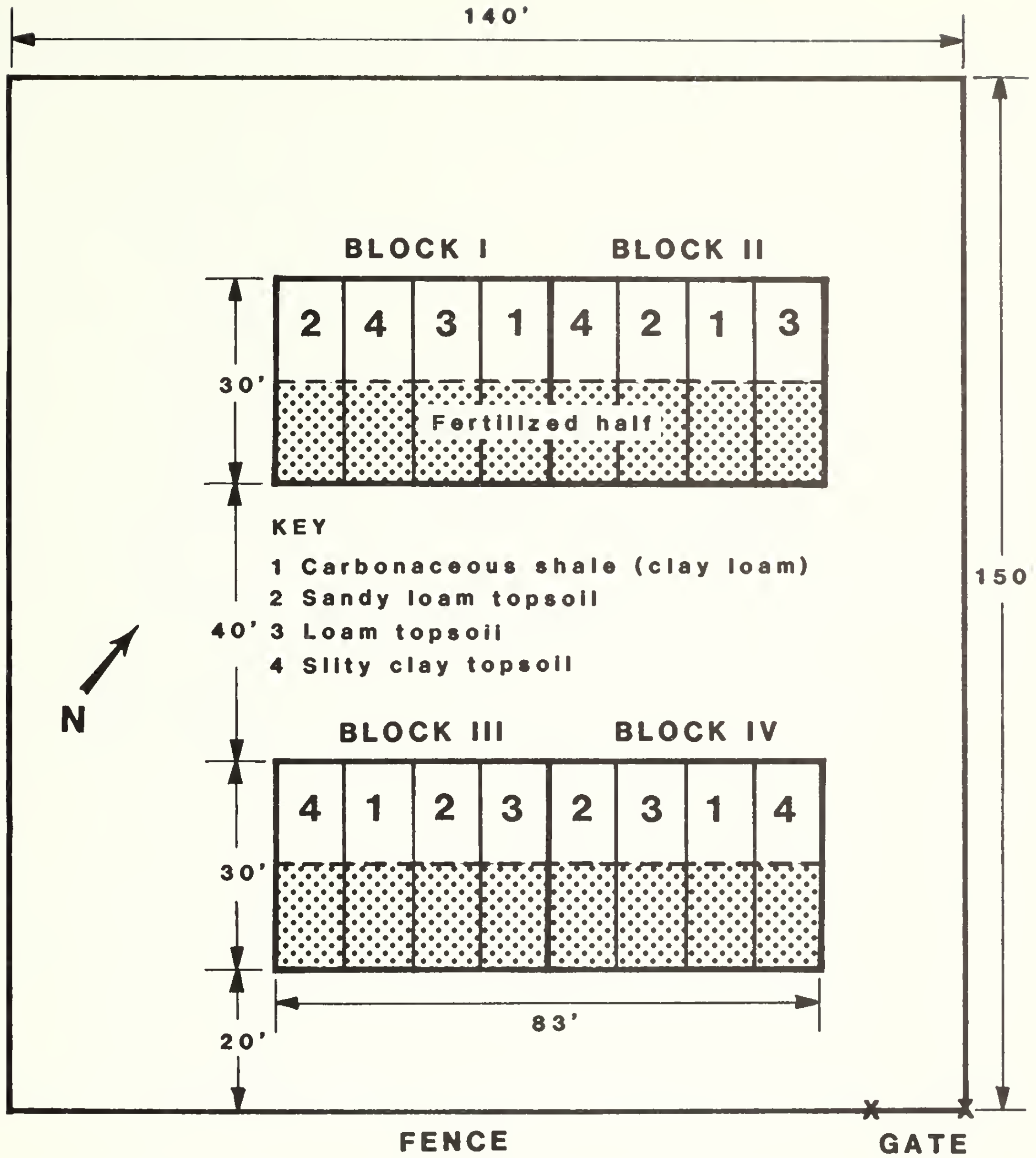

Figure 56.— Field plot design for the study of vegetation establishment on different topsoil-shale overburden combinations, Utah International cooperative study site, Alton coal field.

Block					
BLOCK I				PERA	AMFR
	AMCA	LOTA	CAAR	AMUT	CEMO
	PERA	EPVI	COST	ARTR	CELA
	POFR	ARNO	RHTR	ASGL	RIAU
	PUTR	HEBO	ELAN	CUNE	CHNA
	SPGR	PRVI	CECU	BEFR	ATCA
	ROWO	SACE	KOPR	CELE	SHRO
BLOCK II	AMFR	CUNE	PERA	KOPR	SACE
	RHTR	ARNO	SPGR	HEBO	POFR
	ARTR	CELE	ELAN	SHRO	LOTA
	ATCA	PRVI	AMUT	ASGL	CAAR
	RIAU	COST	BEFR	CHNA	PUTR
	EPVI	ROWO	CEMO	CECU	CELA
BLOCK III	BEFR	CELE	SPGR	ATCA	KOPR
	CAAR	ASGL	PUTR	SACE	POFR
	SHRO	ELAN	COST	CUNE	ARNO
	RIAU	CEMO	EPVI	LOTA	ROWO
	PRVI	PERA	AMFR	HEBO	ARTR
	CELA	AMUT	CHNA	CECU	RHTR
BLOCK IV	RIAU	ASGL	SPGR	ELAN	BEFR
	SACE	PRVI	CHNA	KOPR	CAAR
	COST	SHRO	EPVI	HEBO	CECU
	ARTR	LOTA	RHTR	AMUT	ROWO
	AMFR	CUNE	ATCA	PUTR	CELE
	PERA	POFR	CEMO	CELA	ARNO

144'

75'

N

SPECIES LIST

Planted June 14-16, 1977

AMFR *Amorpha fruticosa*
AMUT *Amelanchier utahensis*
ARNO *Artemisia nova*
ARTR *Artemisia tridentata*
ASGL *Astragalus globiceps*
ATCA *Atriplex canescens*
BEFR *Berberis fremontii*
CAAR *Caragana arborescens*
CECU *Ceanothus cuneatus*
CELA *Ceratoides lanata*
CELE *Cercocarpus ledifolius*
CEMO *Cercocarpus montanus*
CHNA *Chrysothamnus nauseosus*
COST *Cowania stansburiana*
CUNE *Cupressus nevadensis*
ELAN *Elaeagnus angustifolia*
EPVI *Ephedra viridis*
HEBO *Hedysarum boreale*
KOPR *Kochia prostrata*
LOTA *Lonicera tatarica*
PERA *Peraphyllum ramosissimum*
POFR *Potentilla fruticosa*
PRVI *Prunus virginiana*
PUTR *Purshia tridentata*
RHTR *Rhus trilobata*
RIAU *Ribes aureum*
ROWO *Rosa woodsii*
SACE *Sambucus cerulea*
SHRO *Shepherdia rotundifolia*
SPGR *Sphaeralcea grossulariaefolia*

Figure 57.—Field plot design for testing shrub and forb adaptability at the 8-acre study site, Alton coal field. See appendix table 69 for plant symbol key.

BLOCK IV	BLOCK III	BLOCK II	BLOCK I
PEVE	CHNA	CELA	FAPA
HIJA	CELA	HIJA	JUHO (4)
CELE[2]	SPCO	HEBO	ROWO (MT)
SPPA	FAPA	CEPA	ARFI
JUHO (4)	RHTP	CHNA	SPCO
STCO	ROWO (MT)	YUCCA	ACLA
ROWO (MT)	CEBE	PUGL	HIJA
RHTR	JUHO (4)	RHTR	PEVE
FAPA	HEBO	FAPA	CELA
ERCO	PUGL	CELE[2]	COST
HEBO	ROWO (ALTON)	SPPA	STCO
CEPA	YUCCA	ARFI	ERCO
ACLA	STCO	SPCO	ROWO (ALTON)
PUGL	SPPA	ACLA	HEBO
ARFI	ERCO	ROWO (ALTON)	CELE[2]
CELA (4)	HIJA	ERCO	CEBE
CEBE	PEVE	STCO	CEPA
YUCCA	CELE[2]	COST	RHTR
CHNA	ARFI	CEBE	YUCCA
COST	CEPA	JUHO (4)	SPPA
ROWO (ALTON)	ACLA	ROWO (MT)	CHNA
SPCO	COST	PEVE	PUGL

88'

80'

N →

Figure 58.—Field plot design for testing shrub and forb adaptability, Utah International bulk sample site. See appendix table 69 for plant symbol key.

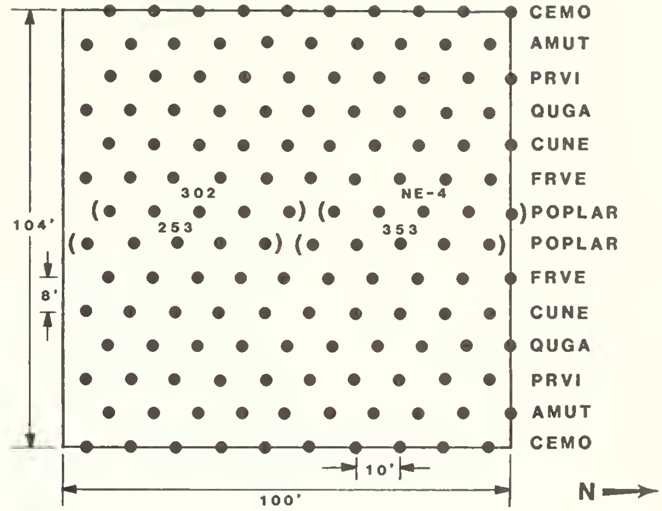

Figure 59.—Field plot design for the "windbreak" portion of the shrub adaptability test, Utah International bulk sample site, Alton coal field. See appendix table 69 for plant symbol key.

BLOCK III	BLOCK II	BLOCK I
70058D	79706	79669
79663	79428	79678
MYTON	79659	79428
79678 YUMA	79667	79706
JOHNSON	79713	79663
7972	79656	79686
79686	79802	79710
U-3675	79726	79776
79802	79686	MYTON
79706	JOHNSON	U-3675
79659	79663	79656
79726	70058D	79659
79669	79685	79713
79656	7972	79667
79428	79776	79685
79776	79678	7972
79685	79710	79802
79713	79669	79726
79710	MYTON	JOHNSON
79667	U-3675	70058D

84'

56'

N →

ACCESSIONS LIST

79706	Holbrook, Navajo Co., AZ
79710	Tuba City, Coconino Co., AZ
79726	Tucson, Pima Co., AZ
79678	Yuma, Yuma Co., AZ
7972	Yuma (35 mi E), Yuma Co., AZ
79656	Joshua Forest, Riverside Co., CA
79663	Delta, Delta Co., CO
79667	Guaymas, Mexico
79713	Tularosa, Otero Co., NM
79659	Bernalillo, Sandoval Co., NM
79685	Adrian, Malheur Co., OR
79686	Nyssa, Malheur Co., OR
U-3675	Ephraim (Excel Canyon), Sanpete Co., UT
70058D	Sanpete Co., UT
79428	Huntington, Emery Co., UT
79776	Jericho sand dunes, Juab Co., UT
79802	Jericho sand dunes (gigas), Juab Co., UT
	Johnson Canyon, Kane Co., UT
	Myton, Duchesne Co., UT
79669	Douglas, Converse Co., WY

Figure 60.—Field plot design for testing Atriplex canescens *ecotypes, Utah International bulk sample site, Alton coal field.*

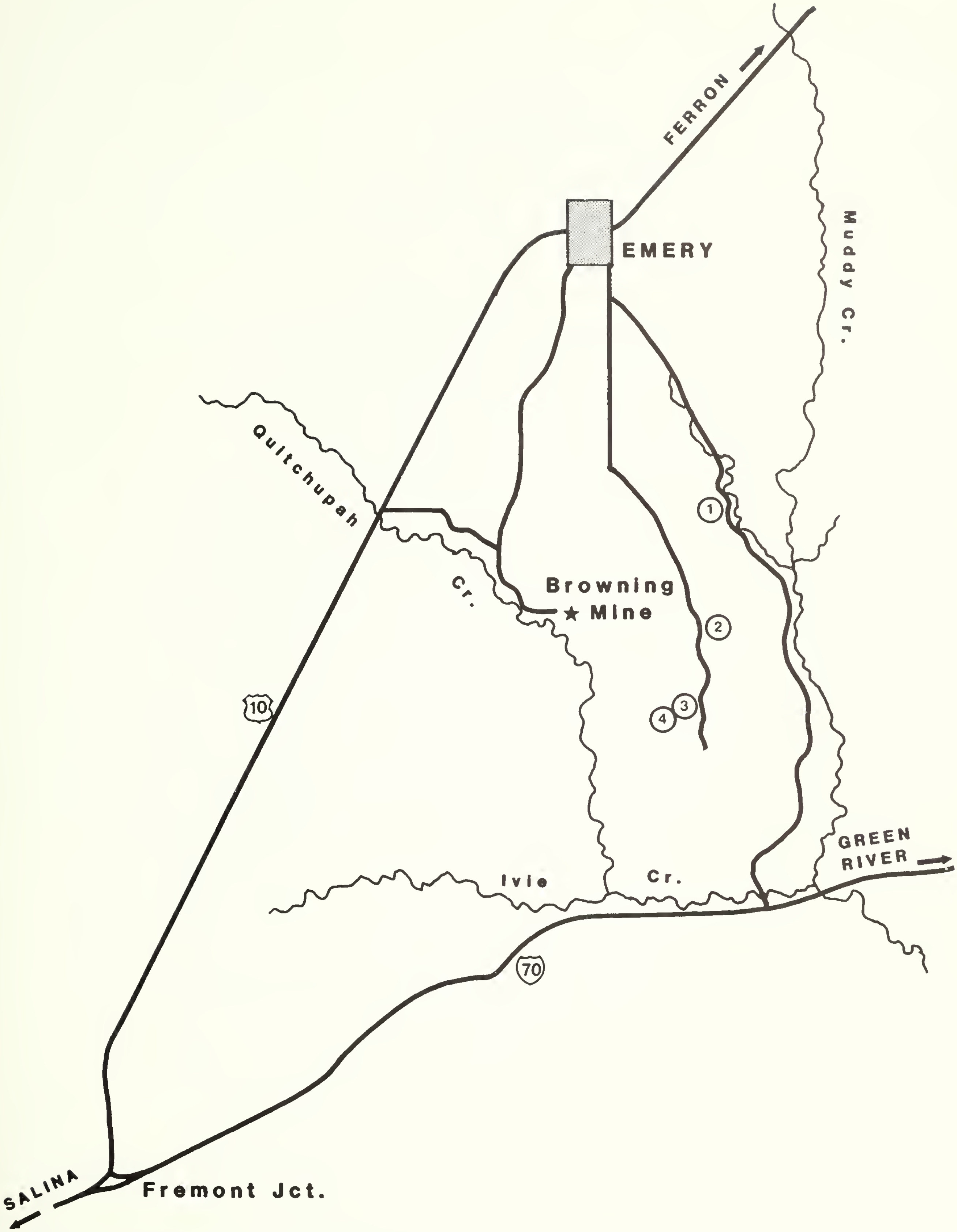

Figure 61.—Location of research sites near Emery, Utah: (1) Blue Gate, (2) Persayo, (3) Penoyer, and (4) Castle Valley.

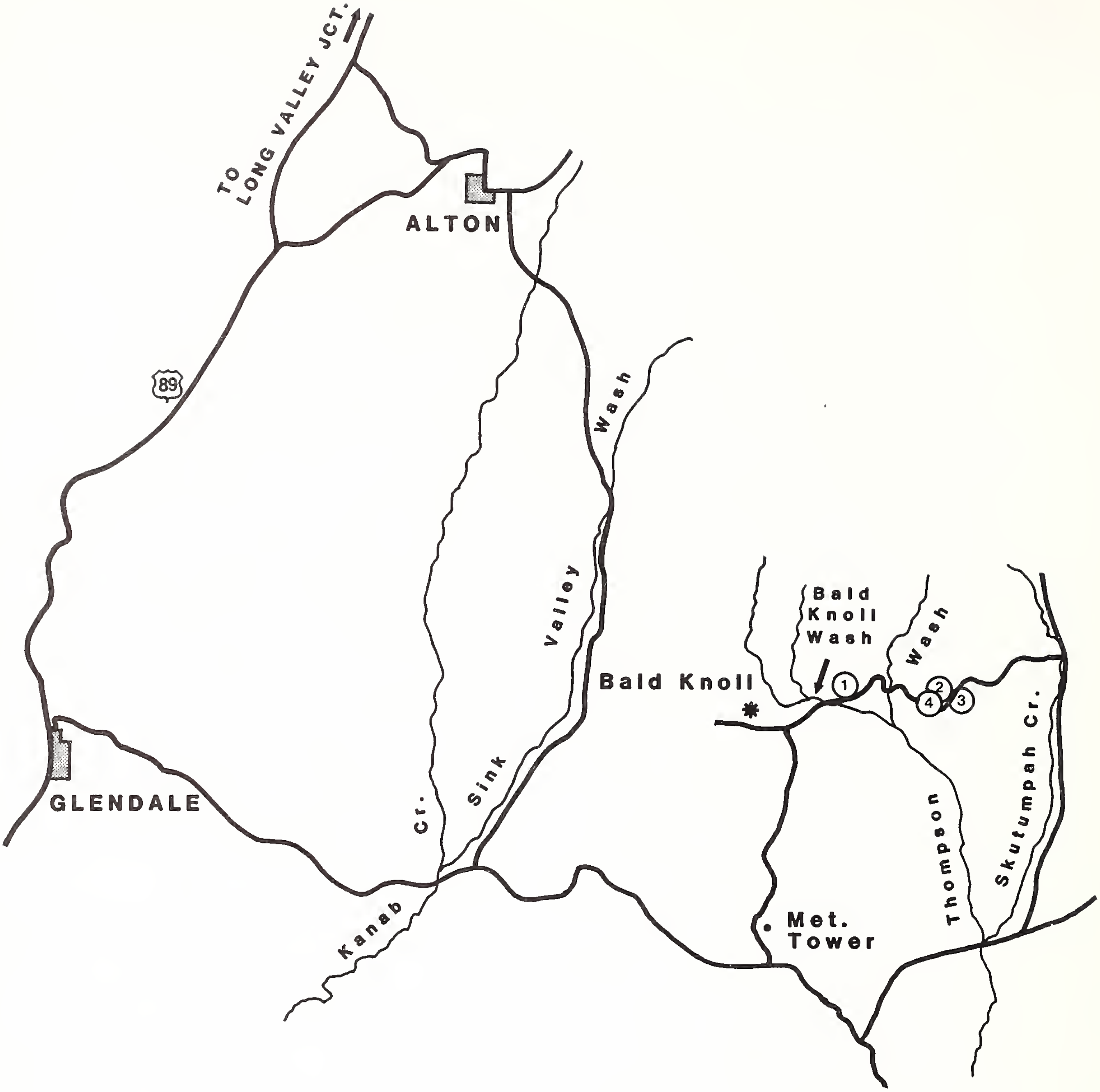

Figure 62.—Location of research sites on the Alton coal field: (1) Utah International, (2) 8-acre, (3) 3-acre, and (4) Utah International bulk sample site.

Ferguson, Robert B.; Frischknecht, Neil C. Reclamation on Utah's Emery and Alton coal fields: techniques and plant materials. Research Paper INT-335 Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1985. 78 p.

Alternative methods of site preparation and broadcast seeding, in conjunction with soil amendments, were evaluated on severely disturbed soil materials of both coal fields during a 6-year study. Potentially useful plant species were planted and studied at several locations. Conclusions on a wide range of studies are presented.

KEYWORDS: coal, reclamation, revegetation, soil amendments, species adaptability, Utah, soil temperature, soil water potential, *Atriplex*, frequency sampling

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